UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES

OF CACHUMA DAM SPILLWAY

CACHUMA PROJECT, CALIFORNIA

Hydraulic Laboratory Report No. Hyd-354

ENGINEERING LABORATORIES BRANCH

DESIGN AND CONSTRUCTION DIVISION
DENVER, COLORADO

January 6, 1954

CACHUMA DAM SPILLWAY
1:60 Scale Model

FOREWORD

Hydraulic model studies of the spillway for Cachuma Dam, Cachuma Project, California, were conducted in the Hydraulic Laboratory of the Bureau of Reclamation at Denver, Colorado, during the period from June 1950 to March 1951.

The recommended design of the spillway, evolved from this study, was developed through the cooperation of the staffs of the Spillways and Outlet Works Section No. 1 and the Hydraulic Laboratory.

During the course of the model studies, Messrs. D. C. McConaughy, C. J. Hoffman and L. M. Stimson of Spillways and Outlet Works Section No. 1 frequently visited the laboratory to observe the model in operation and to discuss test results.

These studies were conducted by Messrs. C. E. Bowers and E. J. Rusho under the supervision of Messrs. A. J. Peterka and J. N. Bradley.

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                    checked by: J. N. Bradley
                                A. J. Peterka

Subject: Hydraulic model studies of Cachuma Dam Spillway--Cachuma
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SUMMARY

The hydraulic model studies discussed in this report were
made to study the flow conditions in the spillway approach channel,
the characteristics of the flow over the spillway crest, the distribu-
tion of flow on the chute, and the performance of the stilling basin.
The results and recommendations contained herein are based on
studies conducted on a 1:60 scale model of the spillway, Figures 3
and 4.

As a result of the model studies, modifications were made
in the right approach wall and in the alignment of the chute training
walls. Also, a 4.5-foot crown, 350 feet long, was placed on the
chute floor to improve the distribution of flow entering the stilling
basin.

Flow in the approach channel was satisfactory except along
the right wing wall, where a large eddy formed and considerable
turbulence occurred due to the earth dike projecting upstream from
the wing wall, Figure 6A. Five different designs of the right wing
wall were tested, Figures 5 and 11. Approach Wall No. 3, Figure
8B, gave the best flow conditions. However, the cost of construct-
ing Wall No. 3 was considered prohibitive and a less costly solution
to the problem was sought. Although some of the performance of
Approach Wall No. 3 was sacrificed, a cheaper design was developed
in Approach Wall No. 5, which gave an acceptable flow pattern.
Therefore, Approach Wall No. 5, Figures 11 and 12, was recom-
mended for construction in the field.

A total of 17 different chute designs was constructed and
tested during the model studies. The chute designs differed in
width of chute, alignment of the training walls, and length and height
of crown to aid in spreading the flow on the chute, Figures 13, 16,
and 17, respectively. The chute studies revealed that the chute
width could be reduced by using a design similar to Alamogordo
Spillway and placing a crown on the chute floor. Figures 18 to 20,

inclusive, show the operation of the recommended chute with various crowns placed on the chute floor.

The stilling basin width and length were found to be adequate. However, various basin wing walls were tested to improve the flow conditions downstream from the basin and to reduce the scour in the outlet channel, Figures 21 to 24, inclusive. Stilling Basin No. 5, which was the preliminary basin with fillets added along the training walls, was chosen as the recommended design. Considerable reduction in the depth of scour was obtained when the right bank of the outlet channel was raised above the maximum tail water elevation, Figure 22A and B.

Figure 26 shows the recommended design resulting from these studies, and Figures 22 and 27 show the recommended design in operation at various discharges.

Extensive model data from the recommended design were obtained to aid in the structural design, to aid in operating the structure, and for correlation later with data from the prototype. These data included discharge capacity curves, Figure 28; pressures on overflow section and vertical curve, Figures 29 and 30; water surface elevations at floatwell intakes, Figure 31; water surface profiles, Figure 32; sweep-out curves, Figure 33; and velocity distribution in the stilling basin, Figure 34.

INTRODUCTION

Cachuma Dam is a part of the Cachuma Project and is located on the Santa Ynez River in Santa Barbara County, California, approximately 19 air-line miles northwest of Santa Barbara, Figure. 1. The principal features of the structure are the dam embankment across the Santa Ynez River, a spillway on the left abutment, and a tunnel outlet works through the left abutment. The dam is a compacted earth structure, approximately 2,975 feet long at the crest, and has a maximum height of approximately 275 feet above the lowest foundation.

The outlet works consists of an intake structure, a 7-foot-diameter horseshoe tunnel containing a 38-inch-inside-diameter steel pipe, and two 30-inch, hollow-jet, control valves. Flow from the outlet works, which is designed for a normal maximum discharge of 250 second-feet, discharges freely into the spillway stilling basin, Figure 2.

The spillway, which is designed for a maximum discharge of 161,000 second-feet, consists of an approach channel; a low overflow gated crest; a chute, 1,059 feet in length, which diverges from a width of 224 feet at the crest to 322 feet at the stilling basin; and a stilling basin and outlet channel, Figure 2. The spillway discharge,

which drops 197 feet between the crest and the stilling basin, is controlled by four 50- by 30-foot radial gates.

Hydraulic model studies of the spillway, discussed in this report, were necessary to study the flow conditions in the approach channel and over the crest, the distribution of flow on the chute, and the stilling-basin performance.

THE 1:60 SCALE MODEL

The spillway was built to a geometrical scale of 1:60 and consisted of a head box containing the approach channel, crest, and reservoir area adjacent to the spillway; a chute connecting the head box with the tail box; and a tail box containing the stilling basin, outlet channel, and a portion of the Santa Ynez river bed, Figures 3 and 4. To compensate for the proportionately greater friction loss in the model, the slope of the model chute was increased by placing the stilling basin 5.23 inches lower than that indicated by strict geometrical relationships.

The spillway crest, chute, and stilling basin were constructed of smooth-finished concrete formed to metal templates, while the training walls were made from wood faced with 30-gauge sheet metal. The spillway piers and the baffle piers were fabricated from wood impregnated with linseed oil.

Water was supplied to the model through a 12-inch horizontal pump and measured by calibrated venturi meters. Tail water elevations in the stilling basin and outlet channel, which were set according to the tail water curve, Figure 33, were controlled by a tail gate located at the downstream end of the tail box.

THE INVESTIGATION

General

The investigation of the spillway was divided into three phases of study; namely, the approach channel studies, the chute studies, and the stilling basin studies. Although the chute studies were conducted more or less simultaneously with the approach channel studies, each is discussed under a separate heading. The approach channel studies involved reshaping the right-wing wall of the spillway approach to streamline the flow entering the spillway. Flow conditions at the left wing wall of the preliminary design, Figure 2, were satisfactory. In developing a satisfactory flow pattern along the right wing wall, five designs were tested, Figures 5 and 11.

To obtain adequate distribution of flow on the chute to produce a satisfactory jump in the basin at all discharges, 17 different chute

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designs were tested. The designs differed in the alignment of the training walls, width of chute, and size and location of crowns on the chute floor, Figures 13, 16, and 17.

The size of the stilling basin in the preliminary design was found to be adequate when the flow entering the basin was properly distributed by realigning the chute training walls and placing a crown on the chute floor. However, five different wing walls at the downstream end of the stilling basin were tested to reduce the depth of scour in the outlet channel, Figures 21, 24, and 25.

Approach Channel Studies

Approach No. 1 (Preliminary). Initially, the preliminary approach channel, Figures 2 and 5A, was installed in the model. At the maximum discharge of 161,000 second-feet, flow in the approach channel was satisfactory except at the right wing wall where objectional flow conditions were observed, Figure 6A. Flow over and around the earth dike projecting out from the right wall resulted in the formation of a large eddy and a very rough water surface in the vicinity of the wall, causing a reduction in the discharge coefficient.

The top of the earth dike was at elevation 751, or 6.6 feet below the maximum reservoir elevation. Thus, at maximum flow, the dike was submerged and part of the flow passed over the dike. The flow over the dike, plus the obstruction by the dike to the flow approaching the spillway, caused the flow disturbances at the right wing wall described above. To improve the flow conditions at the right wing wall, several variations to the preliminary design were tested.

In Design 1-A, the top of the earth dike was raised to elevation 758 feet at the wing wall and sloped downward to the channel floor at elevation 712.5 feet, Figure 6B. This arrangement showed no improvement over Design 1. Flow still passed over the top of the sloping dike and Design 1-A served only to move the adverse flow conditions farther upstream from the spillway.

Since it appeared in the previous tests that the dike obstructed part of the flow and caused some of the objectionable flow disturbances, the earth dike was removed entirely in Design 1-B, Figure 7A. Removal of the dike resulted in no improvement in the flow conditions. Although the roughness of the water surface was reduced, a larger contraction, approximately 6 feet deep, formed along the wing wall.

Approach No. 2. A comparatively long, sweeping wing wall was used in Approach No. 2, in which the radius of the wall was increased from 50 to 117.5 feet and the length from 156 to 222 feet, Figures 5B and 7B. The radically longer wall improved the flow considerably. Except for a slight flow disturbance at the upstream end

of the wing wall, the flow entered the spillway smoothly and with no measurable contraction. While the flow conditions were satisfactory with Approach Wall No. 2, the cost of constructing such a long wall was considered prohibitive.

To find a less costly solution to the problem, Approach Wall No. 2-A was made up of three arcs with radii of 100, 60, and 40 feet, Figure 8A. The over-all length of the wall was 209 feet. Flow conditions along Wall No. 2A were equal to or slightly better than Approach No. 2.

Approach No. 3. The length and radius of the wing wall were decreased further in Approach No. 3, Figures 5C and 8B. The wall was constructed using three arcs with radii of 90, 50, and 25 feet and having a total arc length of 176 feet. Although inferior to Approaches No. 2 and 2-A, the performance of Approach No. 3 was acceptable. A small eddy formed near the upstream end of the wall, but flow along the wall was smooth, with no appreciable contraction.

Figure 9 shows graphically the velocity distribution in the vicinity of the right wing wall. The velocity, which was measured by current meter, varied from approximately 9 feet per second at the upstream end of the wall to over 20 feet per second in the vicinity of the spillway crest.

Approach No. 3 was recommended for use in the prototype design. However, after completing the chute studies described later in this report, the Spillway and Outlet Works Section requested that additional studies be made with the view of devising a less costly wing wall design even at the expense of sacrificing some of the performance obtained with Approach No. 3.

For Approach No. 3-A, the upstream end of Approach Wall No. 3, which projected above the dam embankment, was cut off even with the embankment, Figure 10A. This change resulted in the formation of a large eddy and rough water near the wing wall. It was felt that the flow conditions of the preliminary design were superior to Approach No. 3.

Approach No. 4. Approach No. 4 was similar to the preliminary design except that the radius of the base of the earth dike was increased from 77 to 95 feet and the top of the dike was raised to elevation 758 feet, Figures 10B and 11A. The dike was built up in the model using fine gravel ranging in size from 3/16 to 3/8 inch. Flow conditions around the dike were satisfactory except for a slight surface disturbance on the slope of the dike and dead water immediately downstream from the dike. A 2-hour scour test at maximum flow showed rather severe movement of the gravel near the base of the dike, Figure 10B.

Approach No. 5. A shorter dike with a base radius of 91 feet was used in Approach No. 5, Figures 11B and 12A. Shortening the dike considerably reduced the size of the eddy and the amount of motionless water downstream from the dike at maximum flow, Figure 12B. A 2-hour scour test at maximum flow indicated negligible scour at the base of the dike, Figure 12A. Although the appearance of the flow using Approach No. 3 was superior to that observed with Approach No. 5, the latter design gave an acceptable flow pattern and was less costly to construct., Therefore, Approach No. 5 is recommended for construction in the field.

Spillway Chute Studies

Chute No. 1 (Preliminary). The operation of the preliminary design, Figure 13A, appeared to be fairly satisfactory at the maximum discharge of 161,000 second-feet. The distribution of flow on the chute was fairly uniform and a stable jump formed in the stilling basin, Figure 14A and B. However, for discharges less than 75,000 second-feet, there was a distinct concentration of flow in the center of the chute and stilling basin, Figure 14C. Transverse water surface profiles taken near the downstream end of the chute at Station 14+75 showed that the depth of water near the center line of the chute was greater than that measured near the training walls for all flows, although the depth of water became more nearly uniform as the discharge increased. A scour test of the preliminary design showed severe erosion in the outlet channel near the downstream end of the training walls, Figure 14D.

Chute No. 2. At the request of the design section, parallel training walls were installed in the model, making the width of the chute and stilling basin the same as the crest length, Figure 13B. This design was tested primarily to determine whether the diverging training walls caused the uneven flow distribution in the chute. Figure 15A shows the stilling basin operation at discharges of 161,000 and 25,000 second-feet. The distribution of flow was improved at both discharges with only slightly less unit flow at the outer edges of the stilling basin. At the maximum discharge, the jump was extremely turbulent and extended into the outlet channel. Occasionally the chute blocks were exposed and the jump appeared to be on the verge of sweeping out.

The tests on Chute No. 2 indicated that possibly some of the uneven flow distribution at the lower flows in the preliminary design was attributable to the diverging training walls. The tests also showed that, unless the stilling basin floor was lowered to increase the D_2, a basin width of 224 feet was insufficient to adequately still the flow before it entered the outlet channel.

Chute No. 3. Chute No. 3 was a compromise between the preliminary design and Chute No. 2. The training walls diverged from a chute width of 224 feet at Station 10+26.50 to a width of 274

feet at Station 15+65.00, downstream from which the chute and stilling basin width was constant at 274 feet, Figure 16A. The operation of the stilling basin at maximum flow was improved considerably, as compared to Chute No. 2, Figure 15. The hydraulic jump was less violent and more uniformly distributed. However, when compared with the preliminary design, the jump was more turbulent. At 25,000 second-feet, the flow distribution was inferior to Chute No. 2. The flow again concentrated in the center of the basin.

Following the tests on Chute Nos. 2 and 3, it was decided that a basin width of at least 322 feet was required to adequately still the flow in the basin without lowering the basin floor, and a hump or crown on the chute floor should be investigated to uniformly distribute the flow in the lower range of discharges. As a result of these decisions, the preliminary design (Chute No. 1) was reinstalled in the model and a number of crowns of various sizes and shapes were tested. Although no extensive data was recorded in these studies, the tests showed that a crown was feasible and warranted further investigation.

Chute No. 4. Prior to conducting extensive studies on various crowns, it was decided to further reduce the cost of the chute, if possible, by converging the training walls for a distance downstream from the spillway crest and then diverging the walls to the stilling-basin width of 322 feet. This type of chute design was used successfully on the Alamogordo and Cle Elum Dam Spillways.*

Studies were made on several chute designs similar in plan to the Alamogordo and Cle Elum chutes. From visual observations, Chute No. 4, Figure 16B, was found to give the best flow distribution among those tested.

The operation of Chute No. 4 was very similar to the preliminary design. The flow was distributed satisfactorily at near-maximum discharges but concentrated in the center of the basin for the lower range of flows.

Since Chute No. 4 represented a saving in construction costs over the other acceptable designs which were tested, it was decided to temporarily accept Chute No. 4 and develop a crown which would satisfactorily distribute the flow at all discharges.

Crown studies. Eleven different crowns were tested in Chute No. 4 in developing the recommended design shown in Figure 17D. The various test crowns differed in height of the peak (from 3 to 5 feet), length (from 207 to 350 feet), and location on the chute. Figures 17 to 20, inclusive, show the more important crowns tested and their operation at a discharge of 25,000 second-feet.

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*Hyd-243, "Hydraulic Model Studies on the Alamogordo Dam Spillway."

Hyd-1.1, "Results of Hydraulic Model Studies on the Cle Elum Dam Spillway."

The following table is a summary of the tests on the various crowns. Each crown was evaluated by observing the distribution of flow at discharges of 25,000 and 161,000 second-feet. If the design showed promise of being acceptable, the crown was investigated further by observing the flow at other discharges and making a scour test at maximum discharge.

Table 1

SUMMARY OF CROWN STUDIES

Number	Crown design Length ft	Crown design Height at peak, ft	Reference figures	Maximum depth of scour, ft	Remarks
1	270	3.0	17A, 18A	4	Flow concentrates in center of basin at low flows.
1A	350	3.0	None	Not obtained	Slight improvement over Design 1.
2	350	4.0	17B, 18B	6	Flow distribution satisfactory for discharges above 50,000 cfs. Concentration of flow at lower discharges
2A	350	5.0	18C	Not obtained	Crown too high. Two distinct jets in basin at all flows.
2B	350	4.5	18D	6	Fair flow distribution. Weak spot in center of basin at all flows.
2C	350	3.66	19A	Not obtained	Peak of above crown removed leaving 30-1/2-foot-wide flat top. Weak flow in center of basin at intermediate discharges.
3	350	3.0	17C, 19B	Not obtained	Concentrations of flow in center of basin at low discharges and on outside edges at high discharges.
3A	229	4.5	19C	Not obtained	Peak of crown restored. Unsatisfactory at most flows. Insufficient length of crown.
3B	332	4.5	19D	Not obtained	Crown lengthened and moved downstream. Concentration of flow at lower discharges.
4 (Rec)	350	4.5	17D, 20	2	Fair distribution at low flows and good distribution above 75,000 cfs.

Crown Design 4 was chosen for the recommended design since fair to good flow distribution was obtained at all flows. In addition, a scour test showed that Design 4 resulted in the least depth of scour after operating the model at maximum flow for 2 hours.

Figure 20 shows the operation of the recommended chute design (Chute No. 4 with Crown No. 4 installed) at discharges of 25,000, 50,000, and 161,000 second-feet.

Stilling Basin Studies

General. After the alignment of the chute training walls and the size and location of the crown on the chute had been established, studies were conducted on the stilling basin using various arrangements of wing walls at the downstream end of the stilling basin. Previous tests on the chute and crown showed that the 322-foot width of the basin was required to adequately handle the maximum discharge. These preliminary studies also indicated the length of the basin to be approximately correct. Therefore, the stilling basin studies were concerned primarily with developing an economical wing wall which would permit the flow to enter the outlet channel with a minimum of scour, particularly at the apron corners. Scour tests with the model operating at maximum discharge for either 1/2 or 2 hours were the criterion for judging the various wing wall designs. The tail box was filled with common river sand for use as the erodible material.

Basin No. 1 (preliminary). The preliminary basin was equipped with 90° wing walls 94 feet long, Figure 21A. Results of a scour test for 1/2 hour, Figure 22A, showed an unsymmetrical scour pattern with 6 feet of scour at the downstream end of the right training wall while the depth of scour at the left wall was only 3 feet. The unsymmetrical pattern was attributed to the different heights of the banks of the outlet channel, Figure 2. The maximum elevation of the right bank was approximately 575 feet or 4 feet less than the maximum tail water elevation while the left bank extended well above the maximum tail water. The low right bank permitted a large eddy to form at maximum flow near the right wing wall where the deepest scour occurred. No eddy of any consequence formed at the left wing wall where the maximum depth of scour was only 3 feet.

Next, a scour test of 2-hours duration was made with the right bank filled to elevation 600 feet or approximately 21 feet above the maximum tail water, Figure 22B. Raising the right bank resulted in a comparatively symmetrical scour pattern with scour depths of 2 and 4 feet, respectively, near the right and left wing walls. Since the depth of scour was substantially reduced by raising the height of the right bank of the outlet channel, it was decided to include the higher bank in the recommended design regardless of the type of wing wall adopted. The right bank could be raised with very little expense

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by using the spoil from the basin and channel excavations. Therefore, all subsequent scour tests were made with the right bank raised to elevation 600 feet.

Since the preliminary design called for riprap downstream from the end sill, a layer of gravel, representing 2 to 3 feet of riprap, was placed immediately downstream from the stilling basin. The gravel layer had a prototype thickness of 3 feet 9 inches and extended 100 feet downstream from the stilling basin and wing walls. Figure 22C shows the results of a 2 hour scour test with the riprap in place. Sand was swept back on the gravel apron giving the appearance that the gravel had been eroded. However, when the sand was removed, the gravel apron was found to be intact.

Another scour test was made with the thickness of the riprap increased to 7 feet 6 inches. The scour pattern was very similar to Figure 22C except for slightly different depths of scour at the downstream corners of the stilling basin.

The next scour test was made with the riprap removed and with 45° wing walls, 133 feet long, substituted for the 90° wing walls used in the previous tests. An excellent scour pattern was obtained with the 45° wing walls, Figure 22D. There was negligible scour at the basin cut-off wall and the deepest scour, which was 4 feet, occurred along the wing walls approximately 50 feet downstream from the end sill. Although the scour pattern with the 45° wing walls was the best obtained thus far in the testing, this design required a longer and more costly wall than the 90° wing walls. Therefore, it was decided to test other designs to find a cheaper means of holding the scour to a minimum.

Basin No. 2. A 45° spur wall, extending 30 feet downstream from the 90° walls, was used in Basin No. 2, Figure 21B. While the maximum depth of scour with Basin No. 2 was slightly greater than that obtained with the plain 90° walls of Basin No. 1, the erosion pockets occurred downstream at the end of the spur walls while the erosion at the downstream corners of the basin was negligible, Figure 23A. The spur walls practically eliminated the eddies along the wing walls and, in general, the flow pattern was very good.

Basin No. 3. To reduce the cost of the spur walls, the 45° diagonal wall of Basin No. 2 was removed in Basin No. 3 leaving a 30-foot wall normal to the 90° wing walls, Figure 24A. This wing wall arrangement gave a flow and scour pattern very similar to that obtained with Basin No. 2, Figure 23B.

At this point in the stilling basin investigation, it was decided to use the 90° wing walls of Basin No. 1 in the recommended design. While both the plain 45° wing wall and the 30-foot spur walls were effective in eliminating the eddies which formed along each 90° wall and reduced the scour immediately downstream from the end sill, the

improvements in the flow and scour patterns were considered insufficient to justify the additional cost of these walls over the plain 90° wing walls. Since the plans called for placing riprap downstream from the stilling basin, it was felt that the depth of scour would not be excessive with the less costly 90° wing walls.

Basin No. 4. To determine the effectiveness and optimum size of the chute blocks, scour tests were made with 11-foot high chute blocks in place of the 5-foot high blocks of Basin No. 1 and with the chute blocks removed entirely. Basin No. 4, Figure 24B, was the same as Basin No. 1 except for the size of the chute blocks. Results of a scour test using the higher chute blocks showed an increase in the depth of scour at the corners of the basin, Figure 23C. Otherwise, the scour pattern was similar to Basin No. 1. No differences in the visible flow patterns of Basins No. 1 and 4 were discerned.

With the chute blocks removed, the slope of the hydraulic jump flattened and the jump turbulence extended farther downstream into the outlet channel. The scour test showed the depth of scour to be slightly less but the general scour pattern was similar to Basin No. 1.

Jump sweep-out tests, which are discussed on page 14, showed the 5.5-foot high blocks to have the greatest safety factor before sweep out occurs. Therefore, the chute blocks of Basin No. 1 are recommended.

Basin No. 5. From the standpoints of stilling basin performance and economy, Basin No. 1 appeared to best fit the design requirements and was recommended for construction. However, before the model studies were completed, the design section requested that a scour test be made with 12-foot fillets placed in the stilling basin along the base of the training walls, Basin No. 5, Figure 25. The fillets, which extended from Station 16+97.50 to the downstream end of the stilling basin, were added for structural reasons.

The scour pattern for Basin No. 5 is shown in Figure 23D. The depth of scour at the corners of the stilling basin was increased slightly by installing the fillets, but otherwise the scour pattern was similar to Basin No. 1. Since the area where the deepest scour occurred would be covered with riprap, the scour pockets were not considered serious. Therefore Basin No. 5 is recommended for construction.

A summary of the stilling basin studies is shown in Table 2 below.

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Table 2

SUMMARY OF STILLING BASIN STUDIES

Stilling Basin No.	Type of wing wall	Maximum depth of scour, feet	Remarks
1 (preliminary)	90°	6	No fill at right bank
1 (preliminary)	90°	4	Right bank raised to elevation 600 feet
1 (preliminary)	90°	2 and 4	Three-foot riprap in layer 3'9" thick extending 100 feet downstream from end sill
1 (preliminary)	90°	1 and 5	Three-foot riprap in layer 7'6" thick extending 100 feet downstream from end sill
- -	45°	1 and 4	No riprap. Wing walls 133 feet long
2	30', 45° spur	6	Maximum scour at end of spur wall
3	30', 90° spur	2 and 6	Maximum scour at end of spur wall
4	90°	8	Eleven-foot-high chute blocks
- -	90°	4	Chute blocks removed
5	90°	6	Same design as No. 1 (preliminary), except fillet added at base of training walls

Outlet Works Studies

Since the outlet works discharges into the spillway stilling basin, the design section requested that conduits representing the outlet works be installed in the spillway model to study the general appearance of the jets entering the stilling basin.

The outlet works consist of two 30-inch hollow jet valves which are located near the upstream end of the spillway stilling basin and discharge into the stilling pool at an angle of approximately 53° with the center line of the spillway, see plan of Figure 26. The valves were designed for a total normal discharge of 250 second-feet and may discharge 354 second-feet at maximum reservoir elevation. To make the outlet works the same scale as the spillway (1:60) and geometrically similar to the prototype would require a 1/2-inch conduit and valve which was too small for accurate model results. Therefore, an orifice was used to represent the valve flow. The orifice diameter was such that the jet diameter and velocities were the same as those produced by the valves.

Figure 27A shows the outlet works discharging the total maximum discharge of 354 second-feet. The tail water in the stilling basin was at elevation 561, approximately, or normal for 354 second-feet. Although there is no entrainment of air, the path of the jet may be considered similar to that expected in the prototype. Since the turbulence of the model jets entering the basin was of no consequence in the comparatively large stilling pool, no adverse flow conditions are expected in the prototype.

The Recommended Design

The recommended design of the entire spillway is shown in Figure 26. This design includes Approach No. 5, Figure 11B; Chute No. 4, Figure 16B; Crown No. 4, Figure 17D; and Stilling Basin No. 5, Figure 25. Although Figure 26 does not show the right bank of the outlet channel raised to elevation 600, provisions for raising the right bank as indicated by the model studies were included in the specifications. Figures 20 and 27 show the distribution of flow in the recommended chute and stilling basin for discharges of 25,000, 50,000, 100,000, and 161,000 second-feet.

Spillway discharge curves. Discharge curves for the recommended spillway were obtained from the model for uncontrolled flow and partial gate openings, Figure 28. The coefficient of discharge for the uncontrolled crest at maximum head was determined to be 3.41, while the uncontrolled flow at maximum reservoir elevation of 757.6 feet was found to be 157,000 second-feet, or approximately 2 percent less than anticipated during the design of the structure. The discharge capacity determined from the model was considered to be adequate, however.

Piezometric pressures. Pressures on the spillway over-
flow section and the vertical curve section in the chute were de-
termined by means of piezometers. Eleven piezometers were
spaced at 5-foot intervals on the overflow section and pressures
were observed with the radial gates fully open and at partial gate
openings of 2.5 and 5 feet, Figure 29. The observed pressures
were well above atmospheric with the radial gates fully open. How-
ever, at a gate opening of 2.5 feet, the pressures dropped to ap-
proximately atmospheric in the vicinity of the crest. The lowest
observed pressure was 1 foot below atmospheric at Piezometer No.
6 on the crest of the spillway. For gate openings above 2.5 feet,
the pressures increased with the size of gate openings, until the
pressures shown for free flow were reached.

The pressures observed on the vertical curve section of
the chute from Station 15+65.08 to Station 16+85.08 are shown in
Figure 30 for discharges of 25,000, 100,000, and 161,000 second-
feet. Fourteen piezometers were installed in this region of the
chute and all pressures were observed to be equal to or above at-
mospheric.

Therefore, the curvature of both the overflow section and
the vertical section are satisfactory, and no adverse pressures are
anticipated in these regions of the prototype.

Water surface elevation at float-well intakes. The design
section requested that water surface elevations be obtained at the
float-well intake in each approach wing wall, Elevation B-B, Fig-
ure 2, to determine if the amount of "draw-down" was sufficient to
adversely affect the automatic operation of the radial gates. The
result of this study is shown in Figure 31, in which the water sur-
face above each float-well intake is plotted versus reservoir eleva-
tion, measured well upstream from the spillway where the velocity
of approach was negligible. From Figure 31, it can be seen that
the amount of draw-down at the intake in the left wing wall was ap-
proximately 0.75 foot, while the draw-down at the right wing wall
varied from 4 to 6 feet between reservoir elevations 748 and 758.
The comparatively large draw-down along the right wall was caused
by the earth embankment which extends upstream from the right
wing wall, Figure 12.

As a result of these studies, the location of the left wall
intake was considered satisfactory and no change in its location
was made. However, the amount of draw-down along the right wing
wall was considered too great for satisfactory operation of the auto-
matic gates. Therefore, the right float-well intake was moved up-
stream into the reservoir where the amount of draw-down was in-
significant.

Water Surface profiles. The water surface profile in the
recommended spillway chute was obtained for a discharge of 110,000

second-feet at the normal reservoir elevation of 750 feet. Profiles were obtained along both left and right training walls and are both tabulated and plotted in Figure 32.

Jump sweep-out curves. To determine the stability of the hydraulic jump for different tail water levels, the tail water elevations at which the jump "swept out" and "swept back" into the stilling basin were observed for the range of flows between 80,000 and 161,000 second-feet. Sweep-out and sweep-back curves were obtained with the chute blocks removed and with two heights of chute blocks installed--5.5 feet high (preliminary design) and 11 feet high, Figure 33.

By comparing the tail water curve with the jump sweep-out curves for the three chute block arrangements, it can be seen that, in general, the lowest tail water elevations were required for jump sweep-out and sweep-back when the 5.5-foot high chute blocks were installed. At maximum flow (161,000 second-feet), the tail water could be lowered to elevation 569, or 10 feet below the computed tail water, before the jump swept out. Tail water elevation 570 was required to sweep the jump back into the basin. These tail water elevations are 1 to 4 feet lower than those obtained with the chute blocks removed or with blocks 11 feet high.

Therefore, 5.5-foot high chute blocks are recommended.

Velocity distribution in basin. The lateral distribution of flow in the stilling basin at maximum discharge was determined by obtaining velocity traverses at Stations 18+95 and 19+53, Figure 34. Horizontal velocity curves at elevations 528 and 540 feet were recorded for Station 18+95 and similar curves were obtained at elevations 540 and 550 at Station 19+53. In addition to the horizontal curves, vertical velocity curves were obtained at Stations 18+95 and 19+53 at points on the center line of the basin and 140 feet to the right and left of the center line. These points are designated A, B, C, in the plan of Figure 34.

The maximum observed velocity was 60 feet per second and was recorded at Station 18+95, 100 feet to the right of the center line at elevation 528. A typical vertical velocity curve was obtained at Points A, B, and C where the velocity varied from 0 to maximums of 48, 52, and 55 feet per second, respectively, Figure 34. The vertical velocity curves at Station 19+53 clearly show the reversal of the direction of flow due to the ground roller which forms downstream from the end sill. At Station 19+53, the direction of flow was upstream between elevations 523 and 535 feet and downstream above elevation 535 feet. The maximum velocity upstream was approximately 8 feet per second while the maximum velocity downstream was 22 feet per second.

14

VICINITY MAP

EXPLANATION

————————— PAVED
—————————— IMPROVED
- - - - - - - - GRADED

SCALE OF MILES

INDEX MAP

VICINITY MAP

FIGURE 1
REPORT HYD. 354

FIGURE 2
REPORT HYD. 354

DISCHARGE-TAILWATER CURVES

CONCRETE FINISHES
Surfaces covered by fill:
Formed, F1; Unformed, U1
Exposed surfaces:
Formed, F2; Unformed, U2

NOTE
Reinforcement not shown.

PLAN
SCALE OF FEET

SECTION A-A

SECTION G-G

SECTION D-D

ELEVATION B-B

ELEVATION E-E

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CACHUMA PROJECT-CALIFORNIA

CACHUMA DAM
SPILLWAY
GENERAL PLAN AND SECTIONS

DENVER, COLORADO APRIL 28, 1950

368-D-95

PLAN

SECTION ON CENTERLINE OF SPILLWAY

CACHUMA SPILLWAY
1:60 SCALE MODEL
LAYOUT

Figure 4
Report Hyd-354

CACHUMA DAM SPILLWAY
1:60 Scale Model

FIGURE 5
REPORT HYD 354
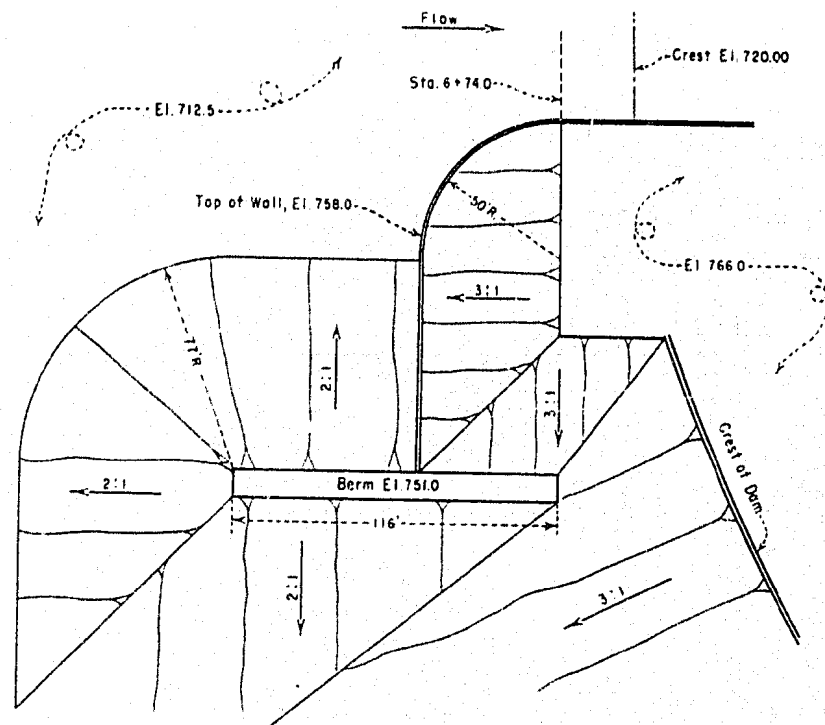
A—APPROACH No.1—PRELIMINARY
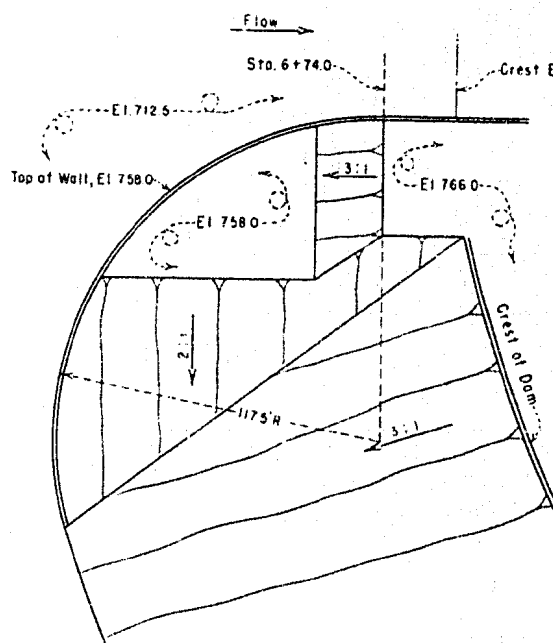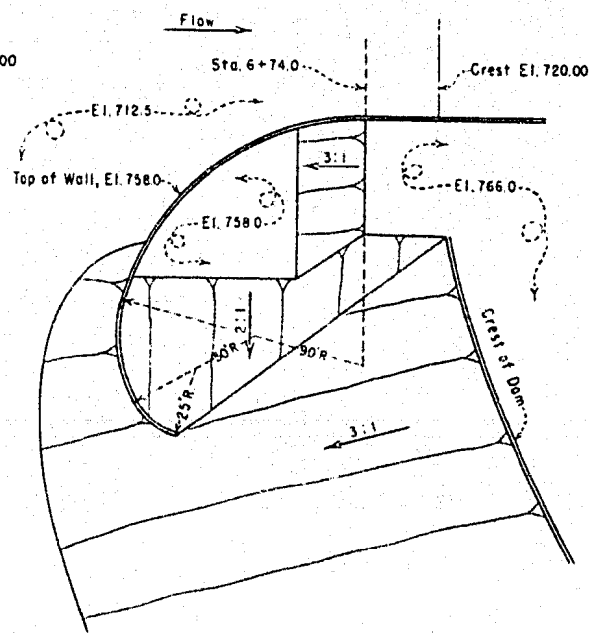
B—APPROACH No.2

C—APPROACH No.3

APPROACH No. 1, 2 AND 3
RIGHT SIDE OF SPILLWAY ENTRANCE
CACHUMA DAM
1:60 SCALE MODEL STUDY

Figure 6
Report Hyd-354
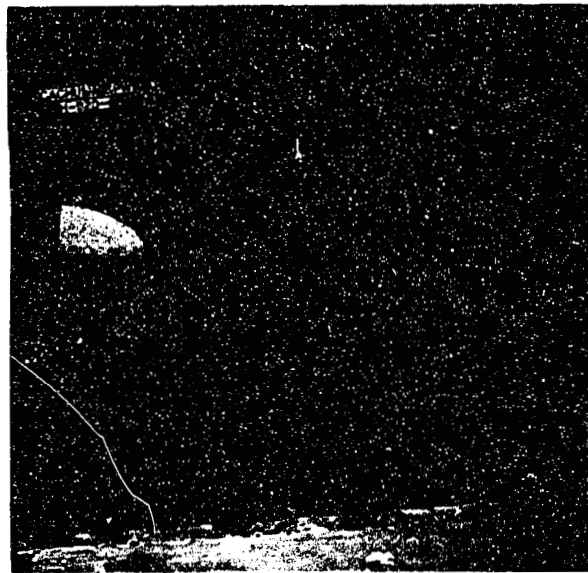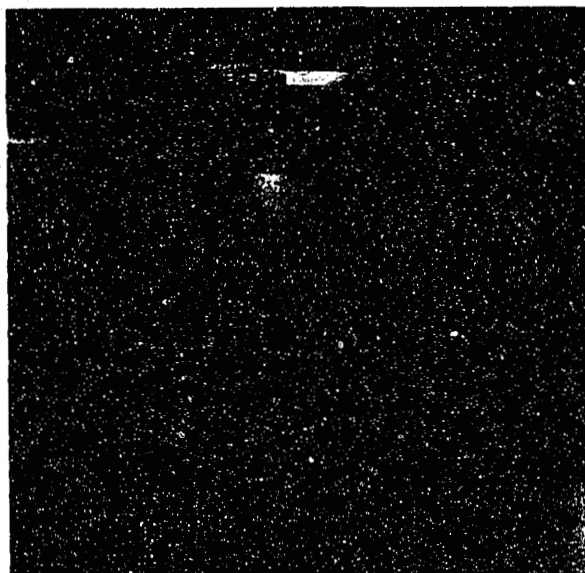
A. Approach No. 1 (Preliminary)
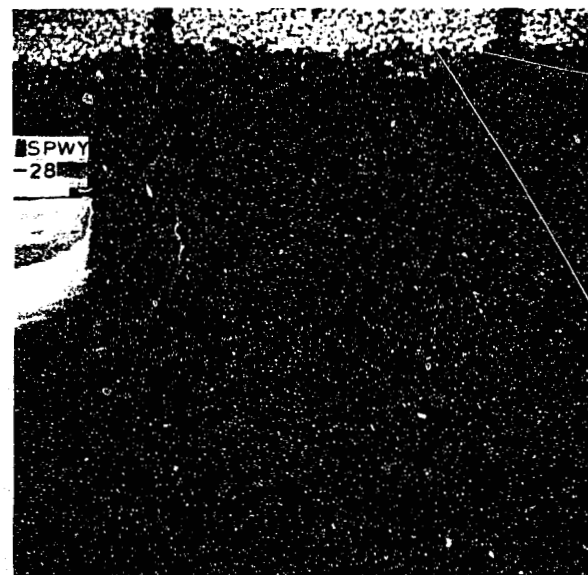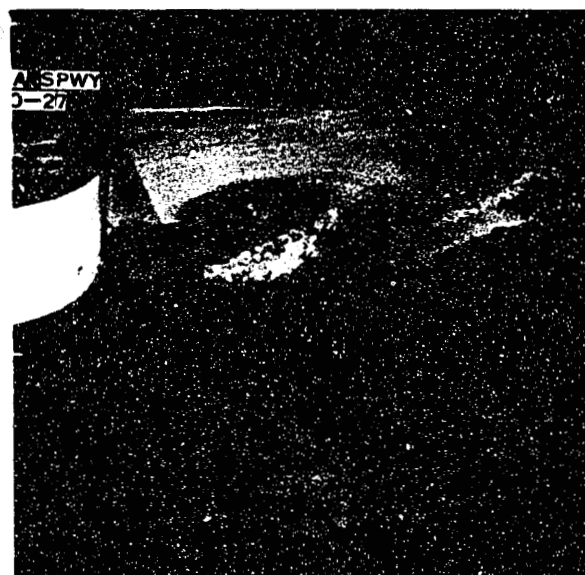
B. Approach No. 1-A

CACHUMA DAM SPILLWAY
Operation of Approach No. 1 and 1-A
Discharge = 161,000 second-feet
1:60 Scale Model

Figure 7
Report Hyd-354
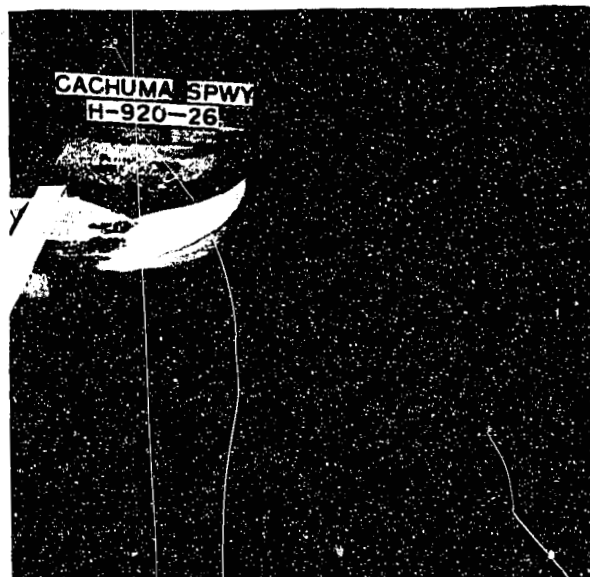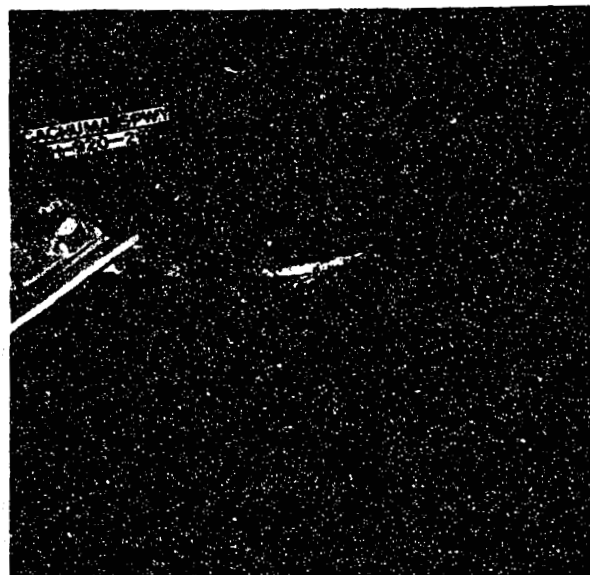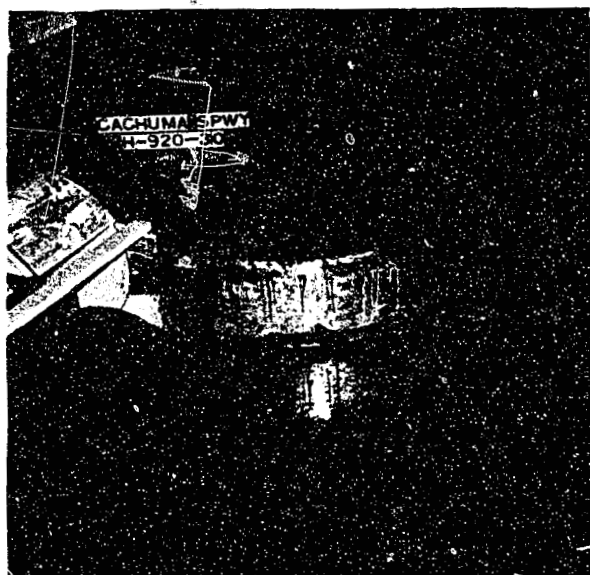
A.   Approach No. 1-B

B.   Approach No. 2

CACHUMA DAM SPILLWAY
Operation of Approach No. 1-B and 2
Discharge = 161,000 second-feet
1:60 Scale Model

Figure 8
Report Hyd-354
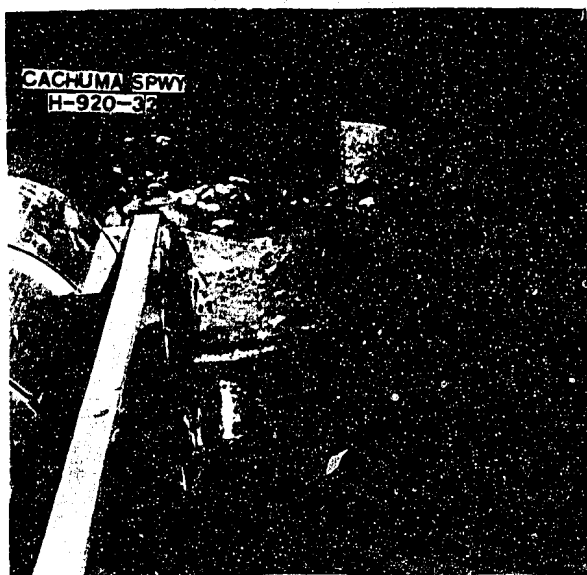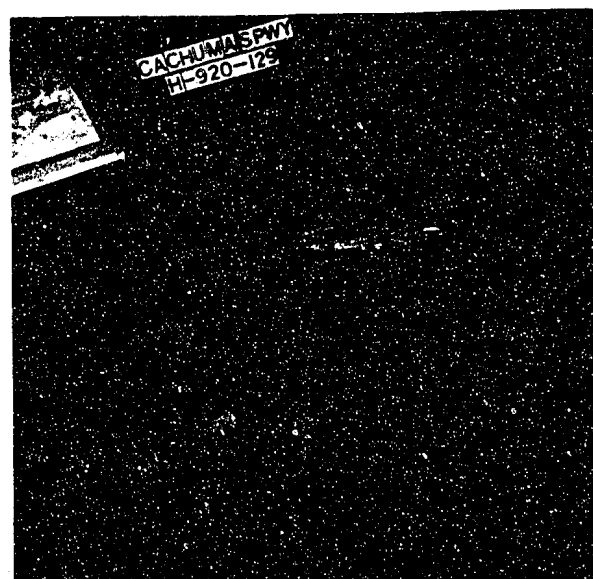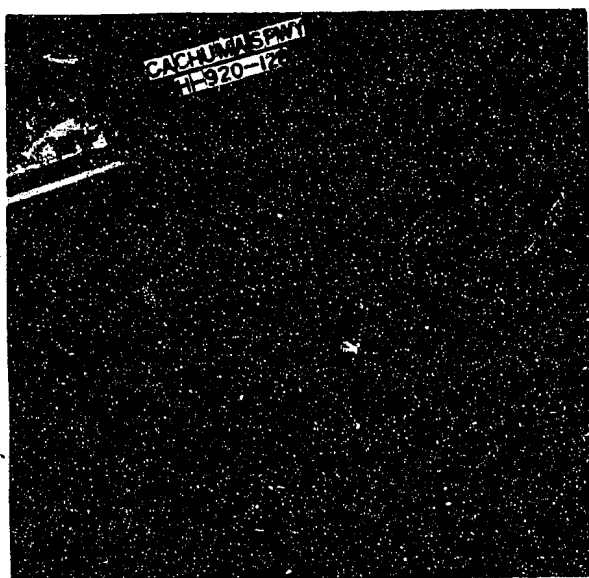
A. Approach No. 2-A

B. Approach No. 3

CACHUMA DAM SPILLWAY
Operation of Approach No. 2-A and 3
Discharge = 161,000 second-feet
1:60 Scale Model

FIGURE 9
REPORT HYD. 354

VELOCITY FT. PER SEC.

CREST

FLOW

APPROACH No. 3

NOTE
Velocities measured 5 feet above
the bottom with a discharge of
161,000 C.F.S. through the spillway.
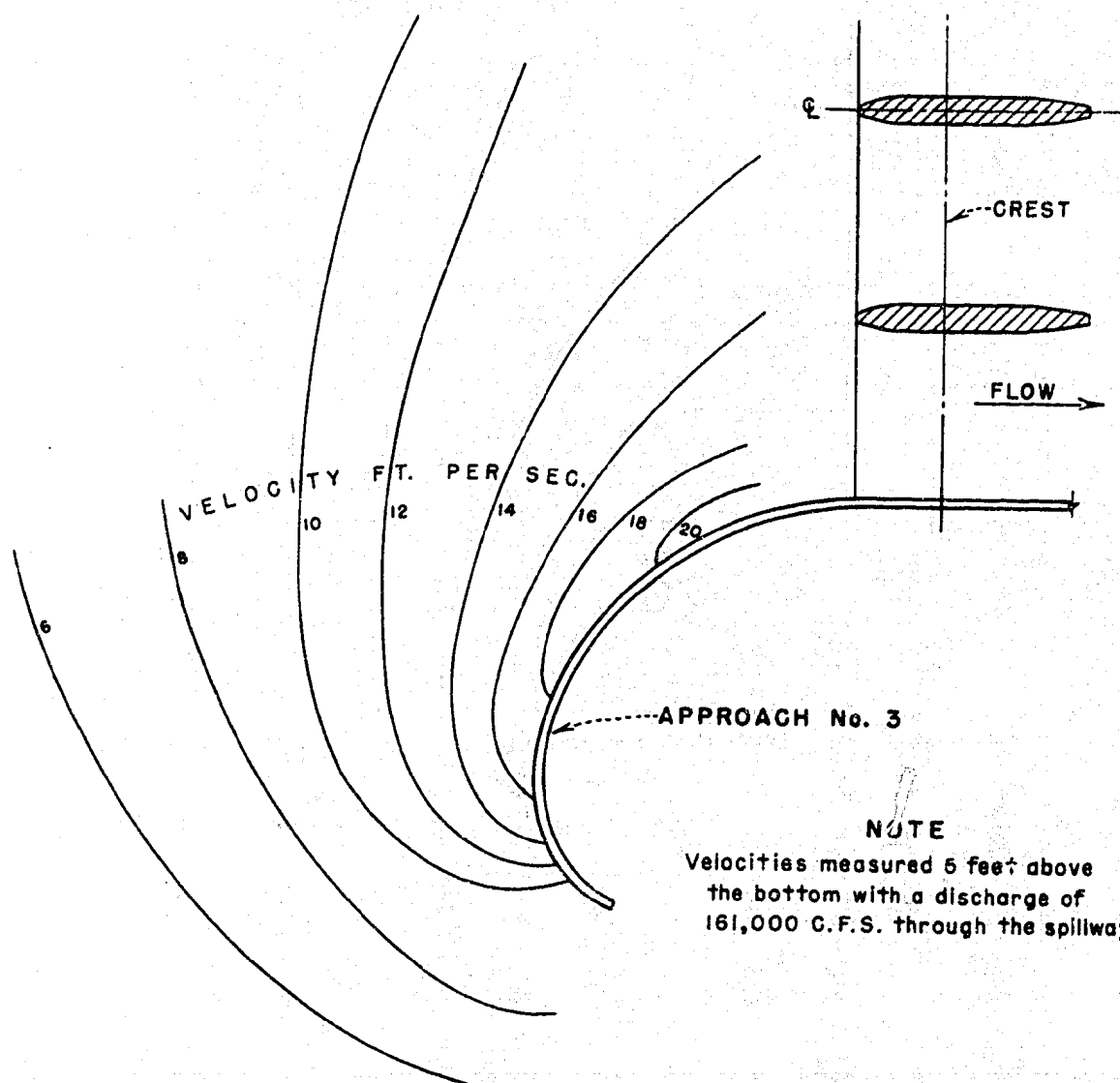
VELOCITY CONTOURS
CACHUMA DAM
1:60 SCALE MODEL STUDY

Figure 10
Report Hyd-354
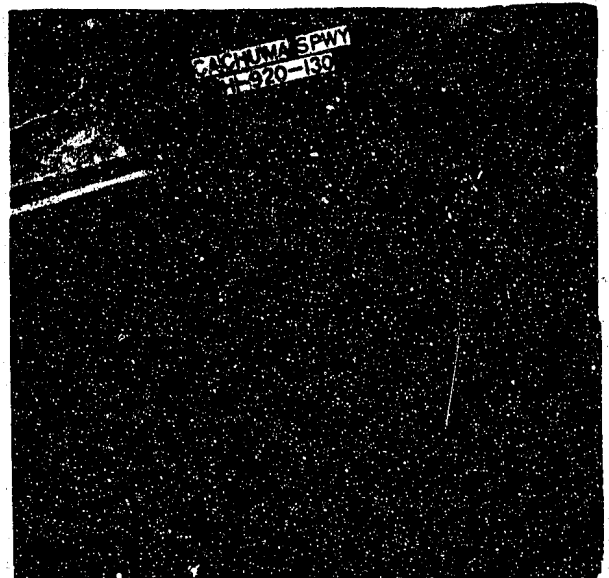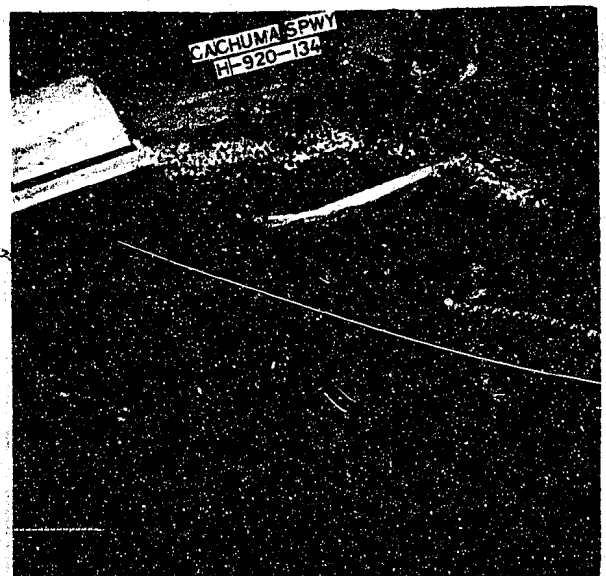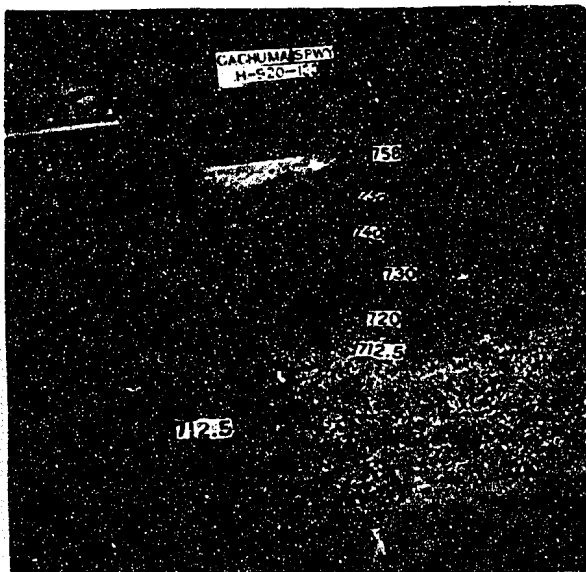
A.   Approach No. 3-A

B.   Approach No. 4

CACHUMA DAM SPILLWAY
Operation of Approach No. 3-A and 4
Discharge = 161,000 second-feet
1:60 Scale Model

FIGURE 11
REPORT HYD. 354

A-APPROACH No.4

B-APPROACH No.5-RECOMMENDED

APPROACH No. 4 AND 5
RIGHT SIDE OF SPILLWAY ENTRANCE
CACHUMA DAM
1:60 SCALE MODEL STUDY

Figure 12
Report Hyd-354
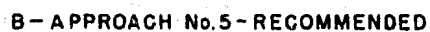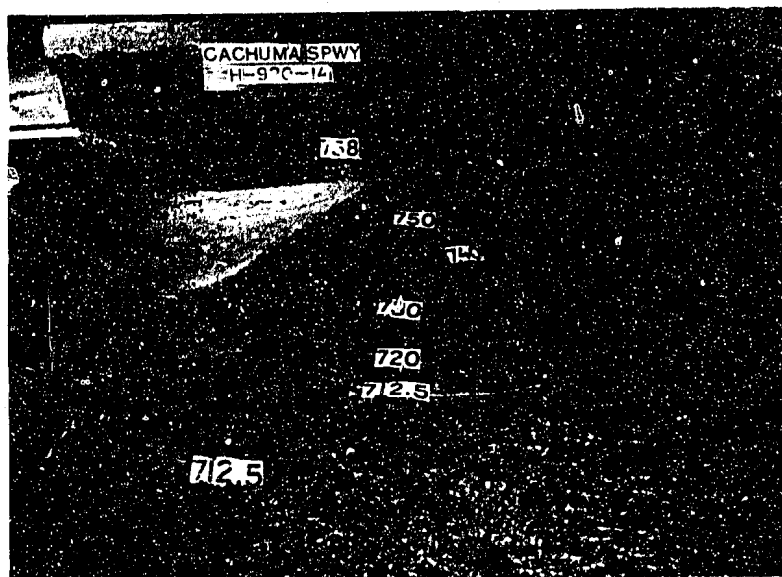
A. Negligible movement of fine gravel
after discharge of 161,000 cfs for
2 hours (model)
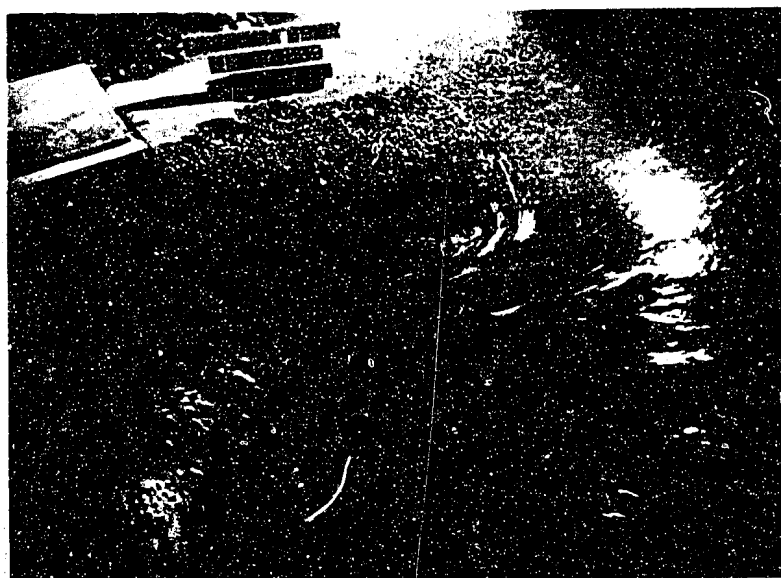
B. Discharge = 161,000 second-feet
with confetti to show stream-lines

CACHUMA DAM SPILLWAY
Approach No. 5 (Recommended)
1:60 Scale Model
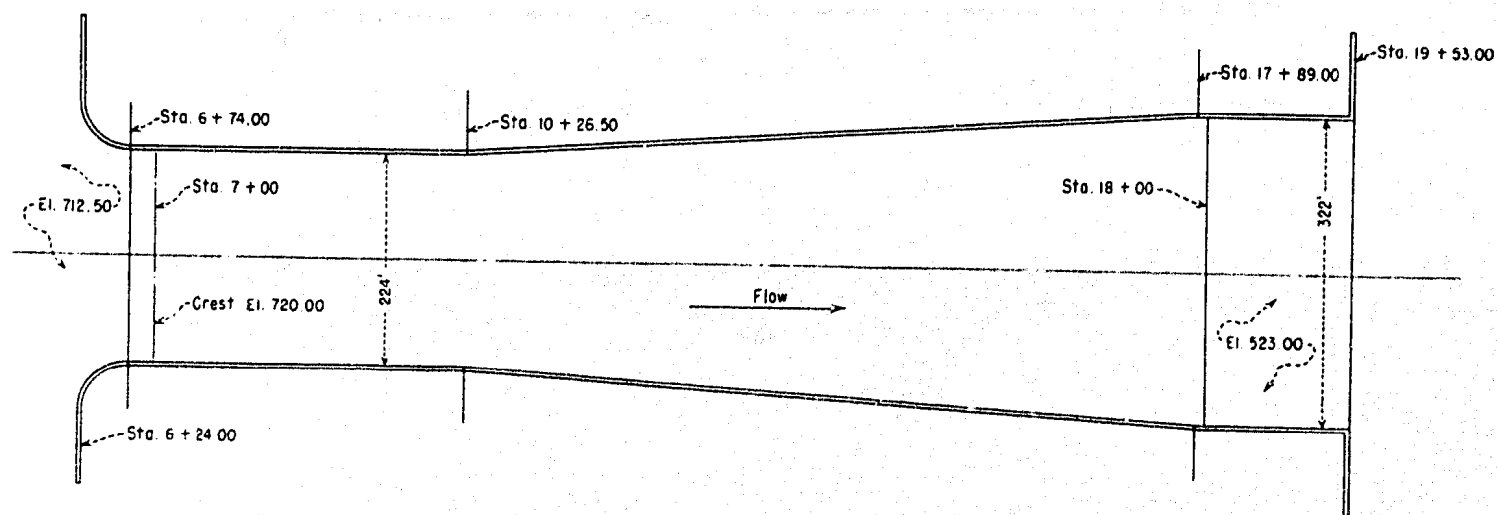
A. CHUTE NO. I - PRELIMINARY
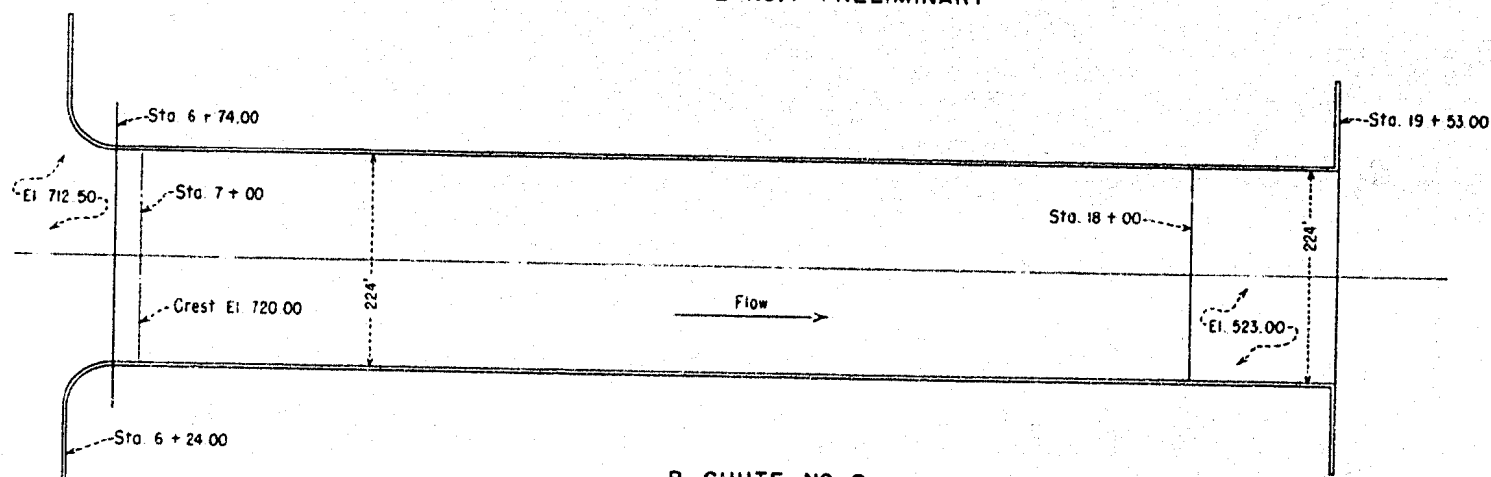
B. CHUTE NO. 2

SPILLWAY CHUTE No. I AND 2
TRAINING WALL ALIGNMENT
CACHUMA DAM
1:60 SCALE MODEL STUDY

FIGURE 13
REPORT HYD. 354

Figure 14
Report Hyd-354

A. Flow in chute
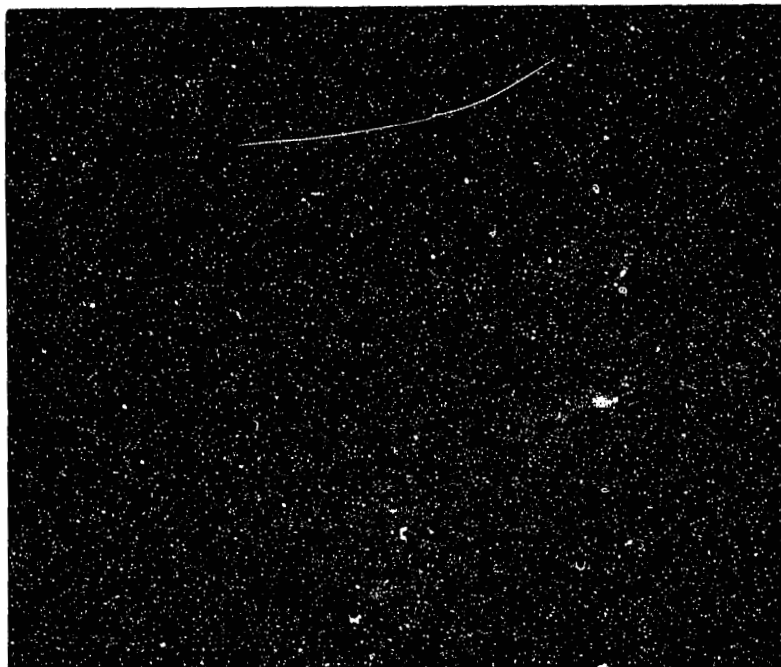
B. Discharge of 161,000 second-feet in stilling basin

C. Discharge of 25,000 second-feet in stilling basin.
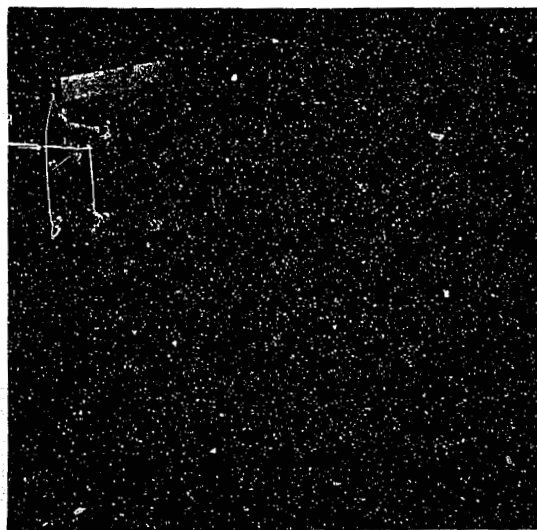
D. Scour pattern after discharge of 161,000 second-feet for 30 minutes.

CACHUMA DAM SPILLWAY
Operation of Chute No. 1 - Preliminary
1:60 Scale Model

Figure 15
Report Hyd-354
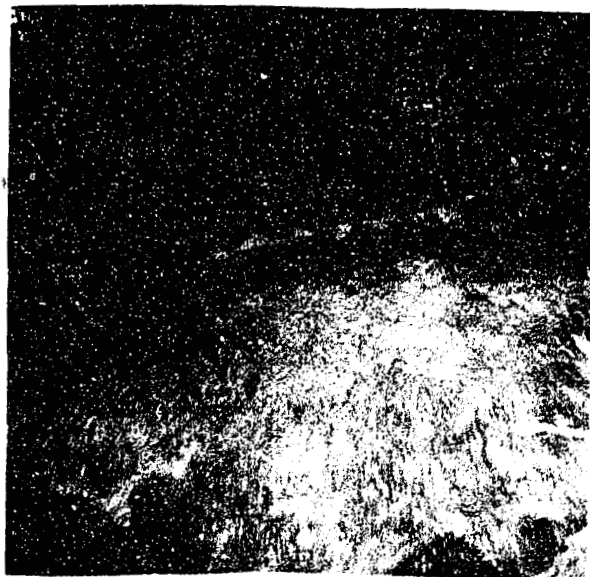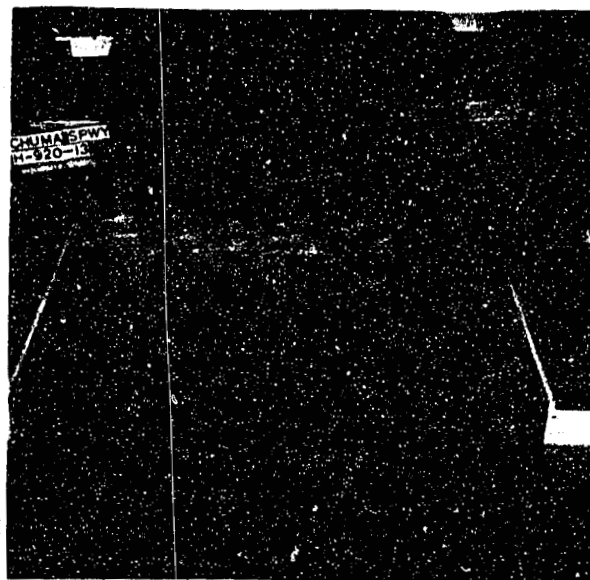
161,000 second-feet   25,000 second-feet

A. Chute No. 2
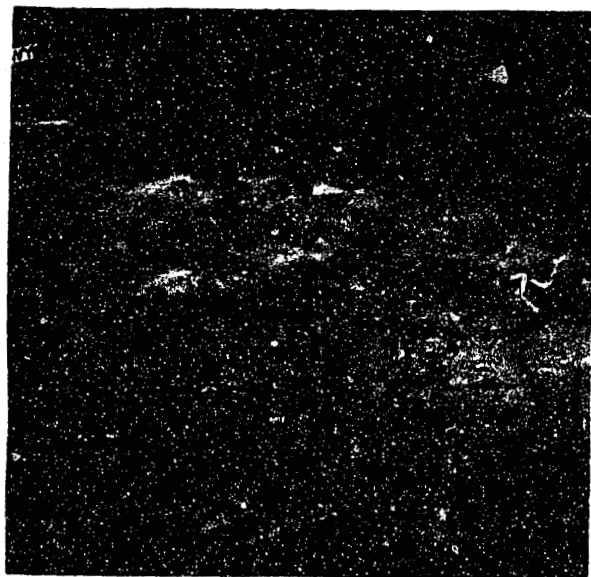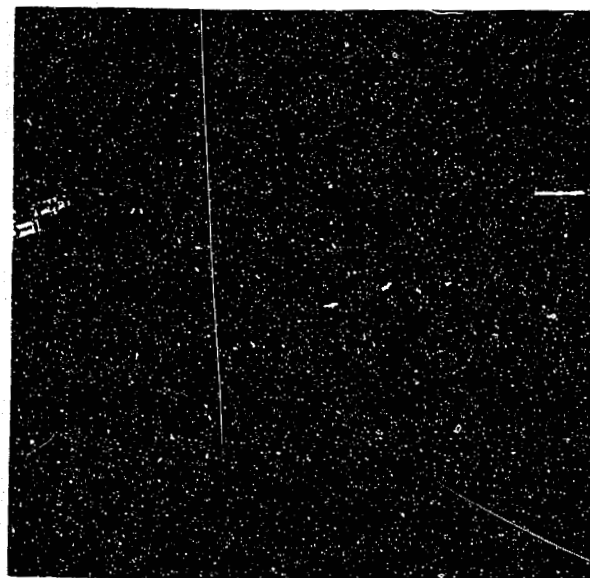
161,000 second-feet   25,000 second-feet

B. Chute No. 3

CACHUMA DAM SPILLWAY
Operation of Chute No. 2 and 3
1:60 Scale Model
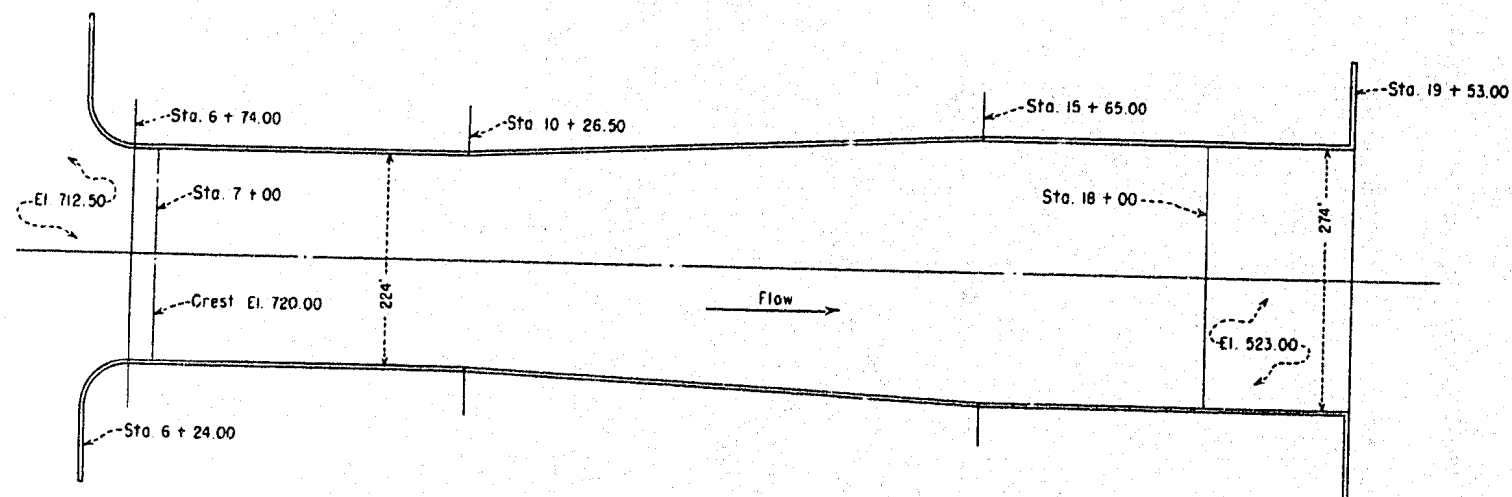
A. CHUTE NO. 3
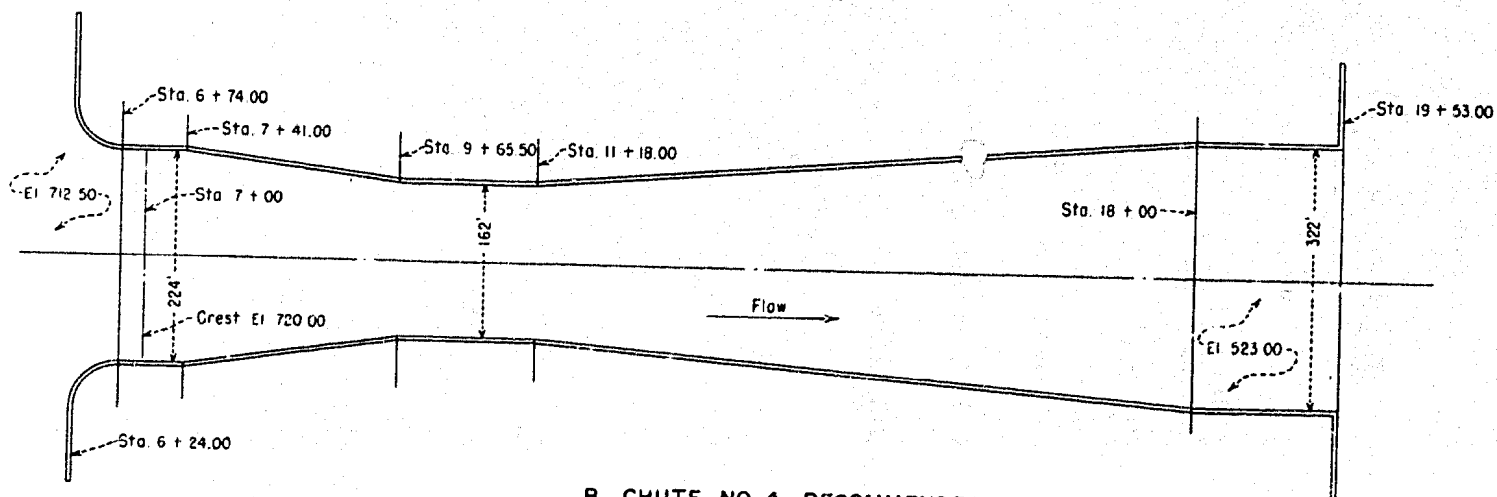
B. CHUTE NO. 4 –RECOMMENDED

SPILLWAY CHUTE No. 3 AND 4
TRAINING WALL ALIGNMENT
CACHUMA DAM
1:60 SCALE MODEL STUDY

FIGURE 16
REPORT HYD. 354

FIGURE 17
REPORT HYD. 394
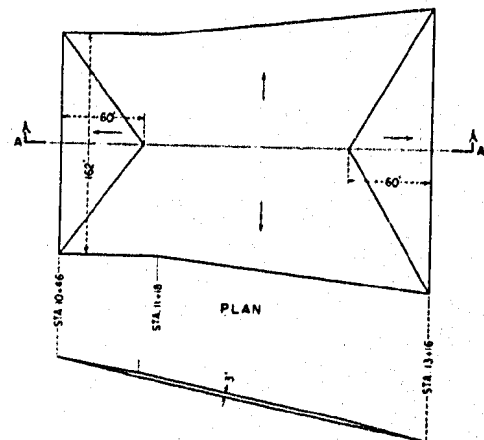
SECTION A-A
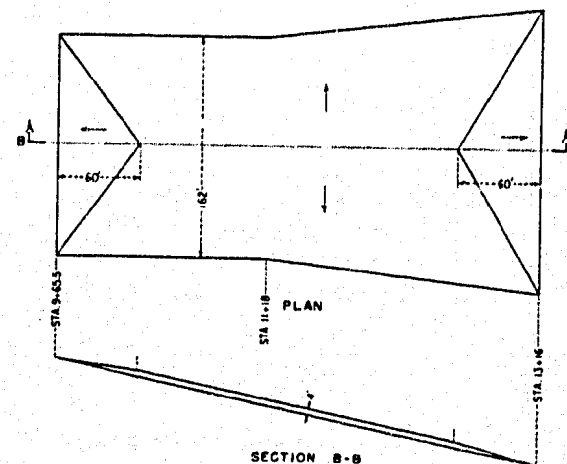
A. CROWN No. 1

SECTION B-B

B. CROWN No. 2
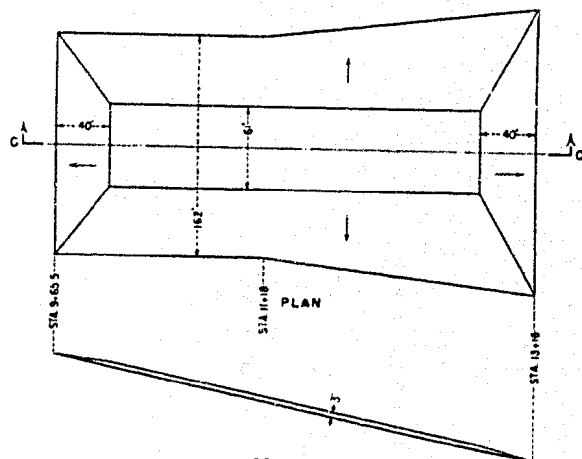
SECTION C-C

C. CROWN No. 3
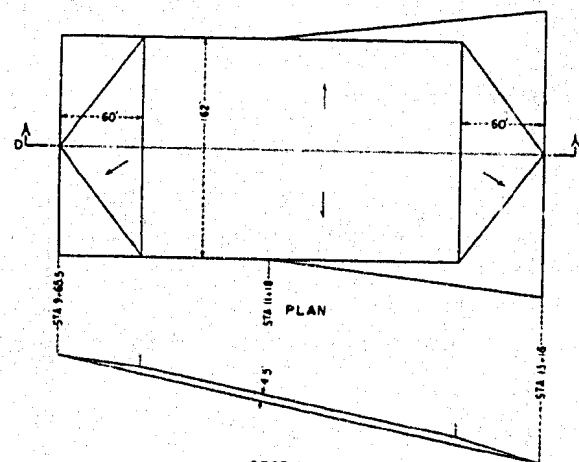
SECTION D-D

D. CROWN No. 4 - RECOMMENDED

SPILLWAY CHUTE CROWNS
CACHUMA DAM
1:60 SCALE MODEL STUDY

Figure 18
Report Hyd-354
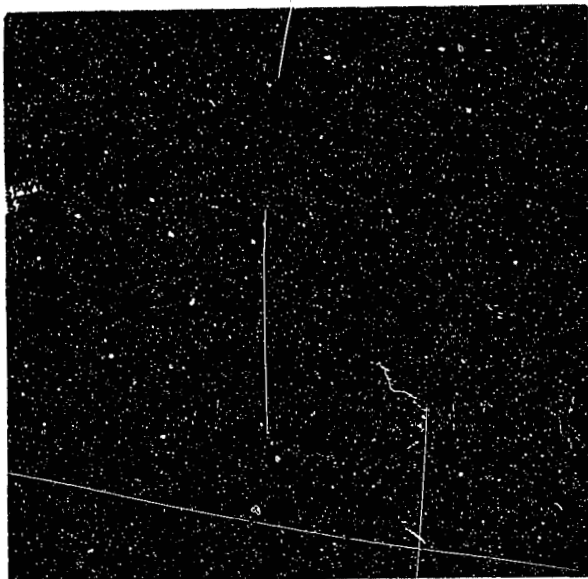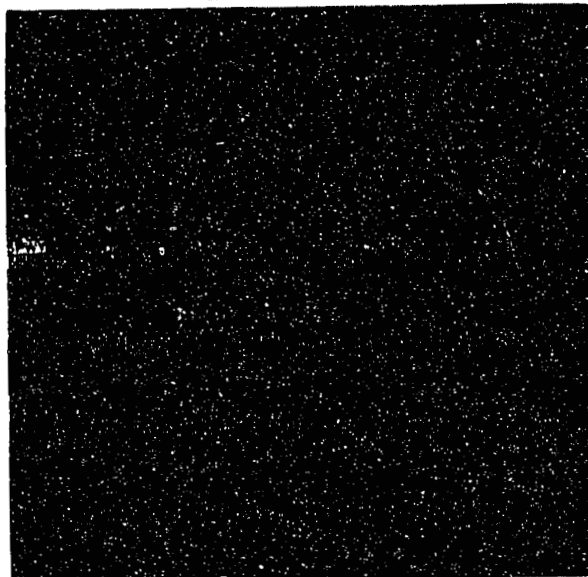
A. Crown No. 1

B. Crown No. 2
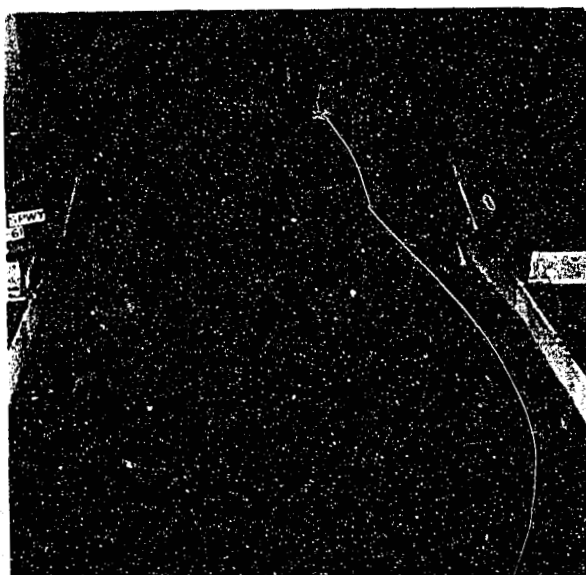
C. Crown No. 2A. Height of crown No. 2 increased to 5 feet

D. Crown No. 2B. Height of crown No. 2 increased to 4.5 feet.

CACHUMA DAM SPILLWAY
Operation of Chute No. 4 with Crown No. 1 and 2
Discharge = 25,000 second-feet
1:60 Scale Model

Figure 19
Report Hyd-354
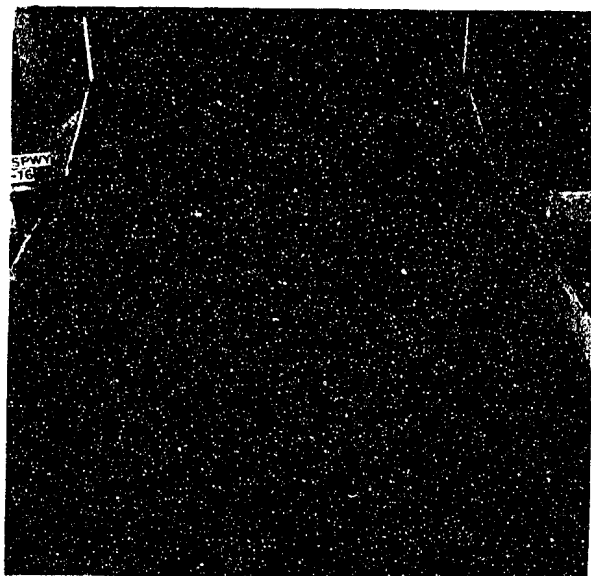
A. Crown No. 2C. Peak of crown No. 2B removed leaving 30-1/2-foot-wide flat top.
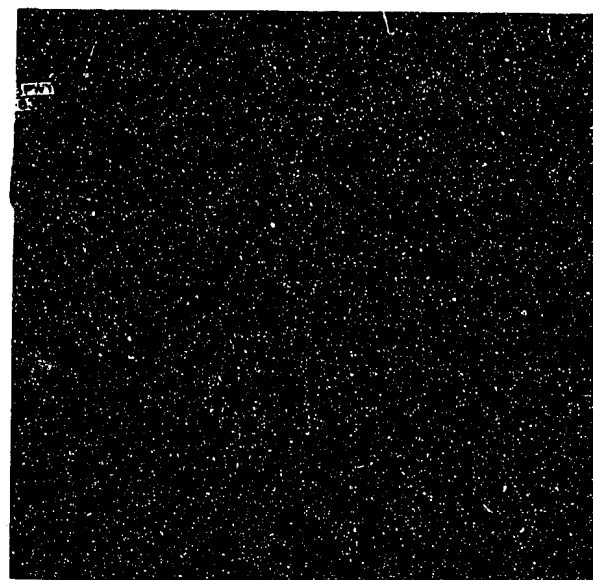
B. Crown No. 3
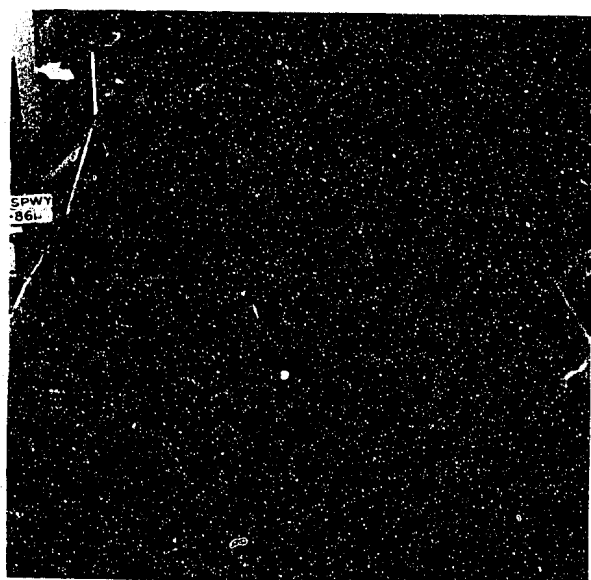
C. Crown No. 3A. (Peaked crown 229 feet long and 4-1/2 feet high.)
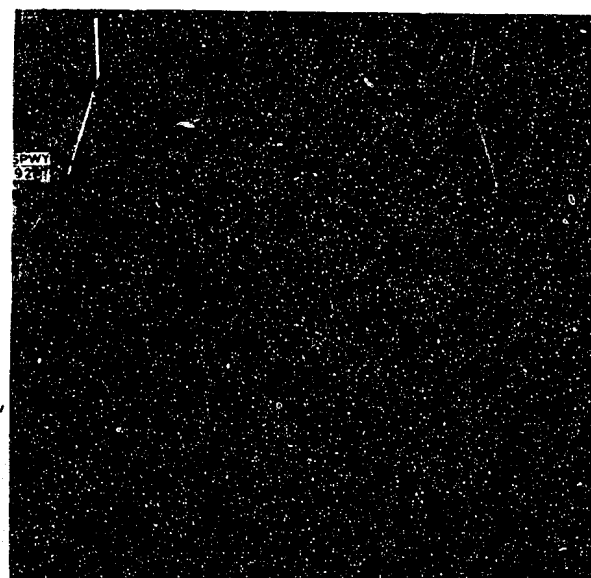
D. Crown No. 3B. (Peaked crown 322 feet long and 4-1/2 feet high.)

CACHUMA DAM SPILLWAY
Operation of Chute No. 4 with Various Crowns
Discharge = 25,000 second-feet
1:60 Scale Model

Figure 20
Report Hyd-354

A. Flow distribution on chute
Discharge = 161,000 cfs.
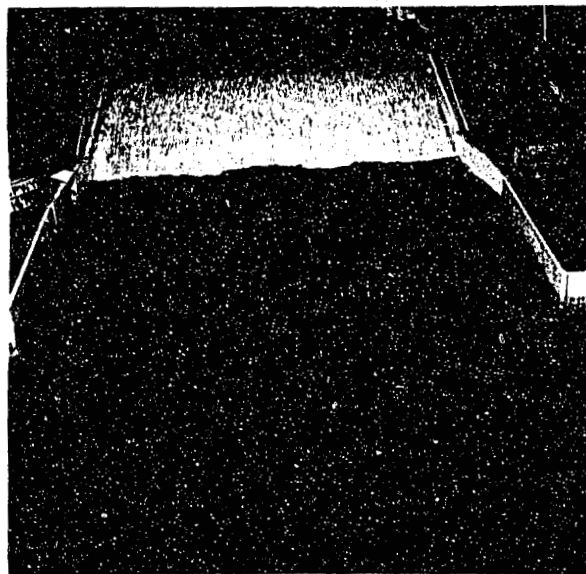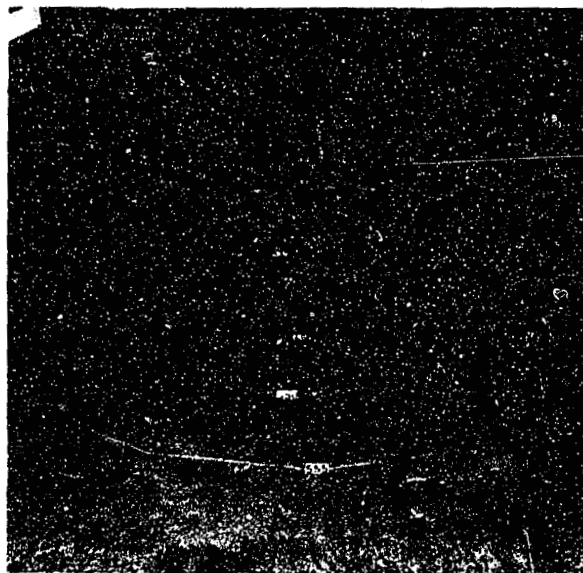
B. Discharge = 25,000 cfs
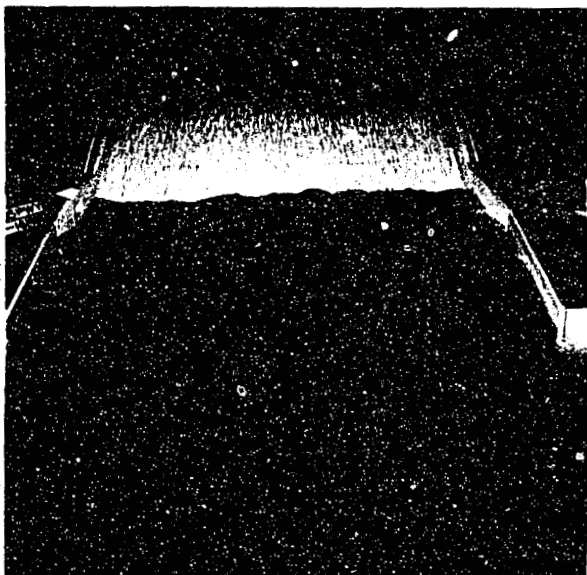
C. Discharge = 50,000 cfs
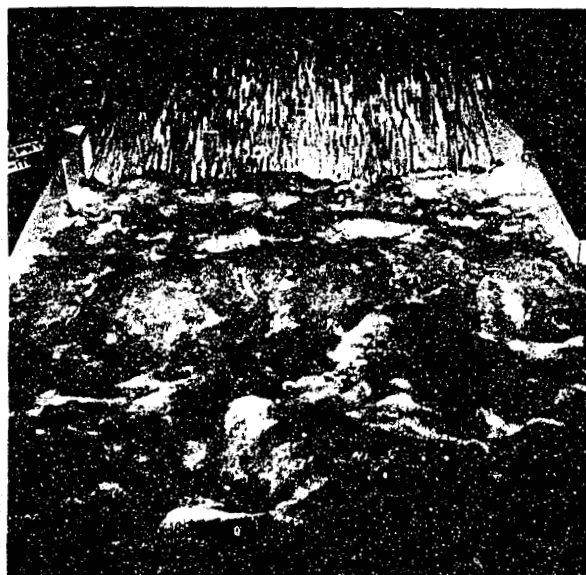
D. Discharge = 161,000 cfs

CACHUMA DAM SPILLWAY
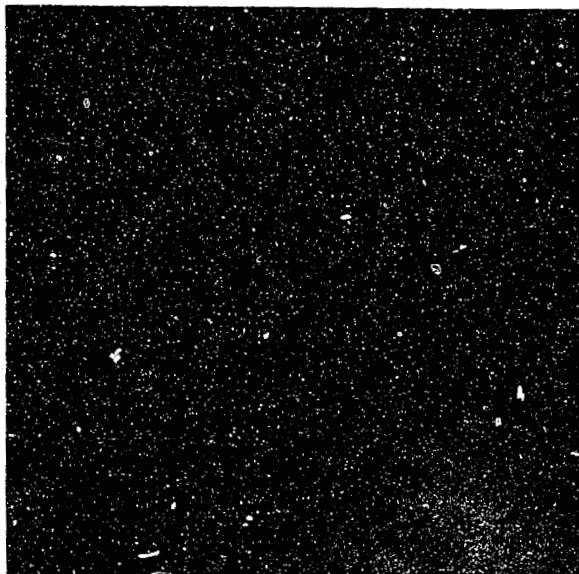Operation of Chute No. 4 with Crown No. 4 (Recommended)
1:60 Scale Model

PLAN

ELEVATION
A. BASIN No. I - PRELIMINARY

PLAN

ELEVATION
B. BASIN No. 2
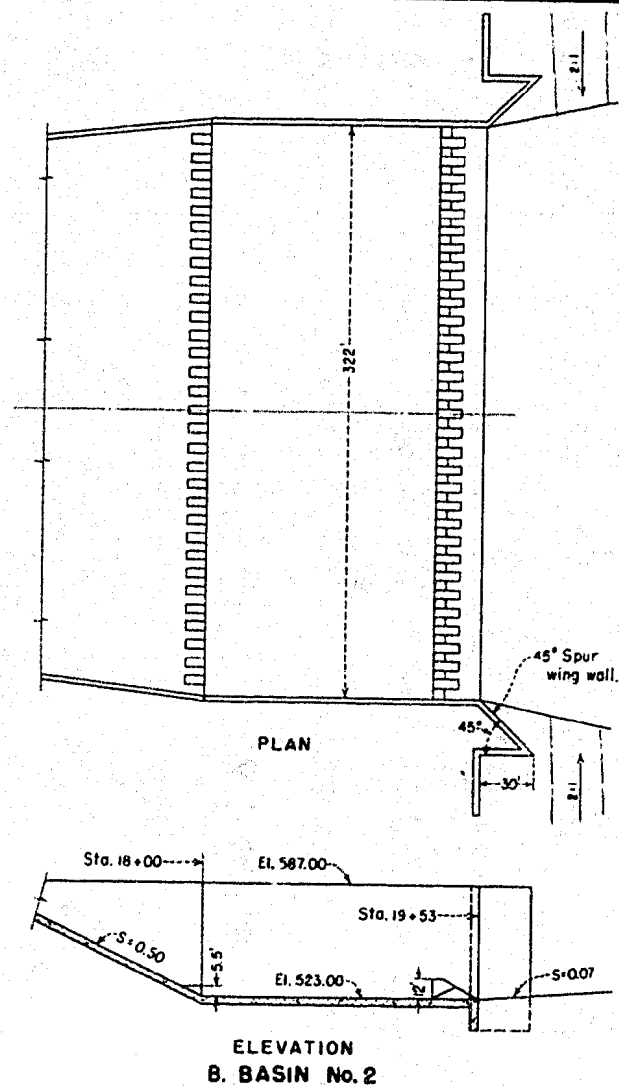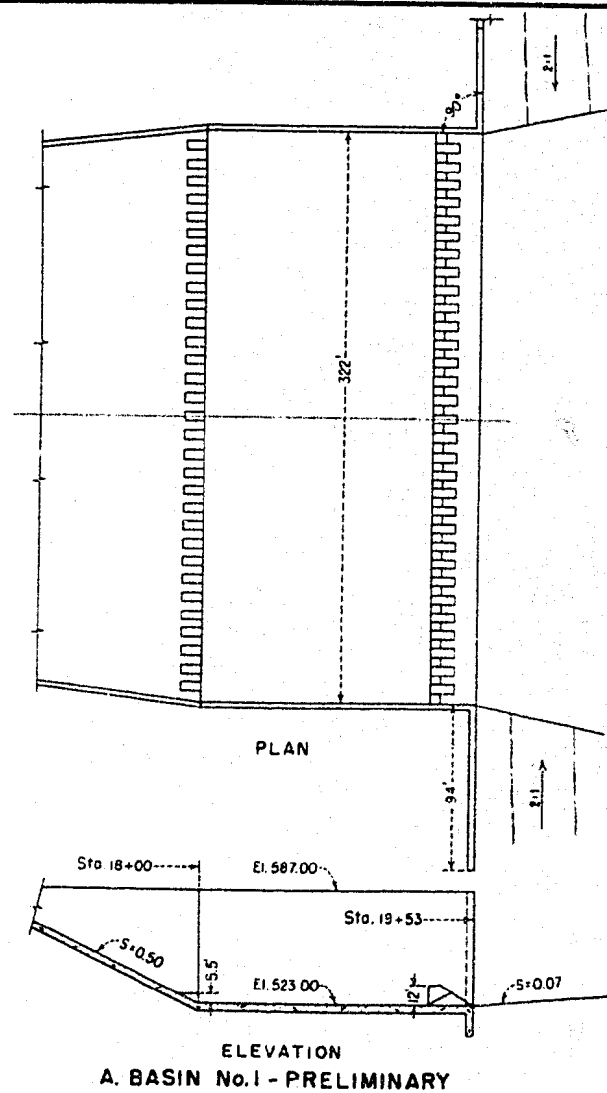
STILLING BASINS No. I AND 2
CACHUMA DAM SPILLWAY
1:60 SCALE MODEL STUDY
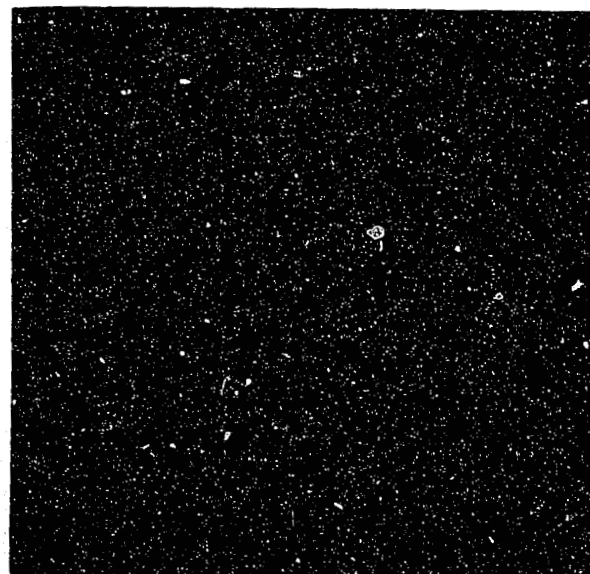
Figure 22
Report Hyd-354

A. Basin No. 1 (Preliminary)
(1/2-hour scour test)

B. Basin No. 1 with right bank
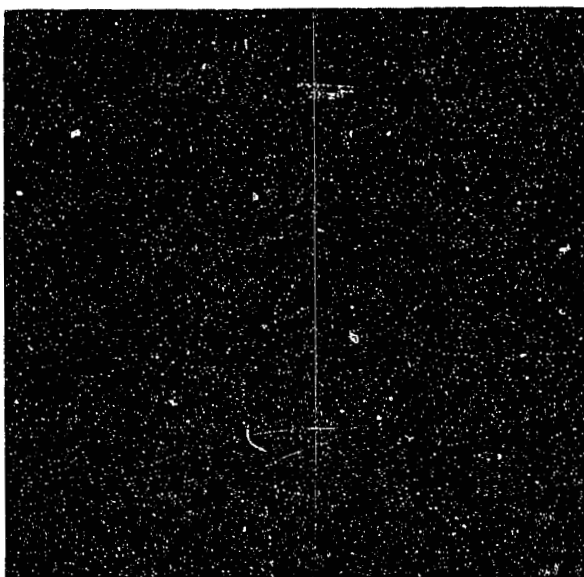raised to Elev. 600 feet
(2-hour scour test)

C. Basin No. 1 with riprap placed
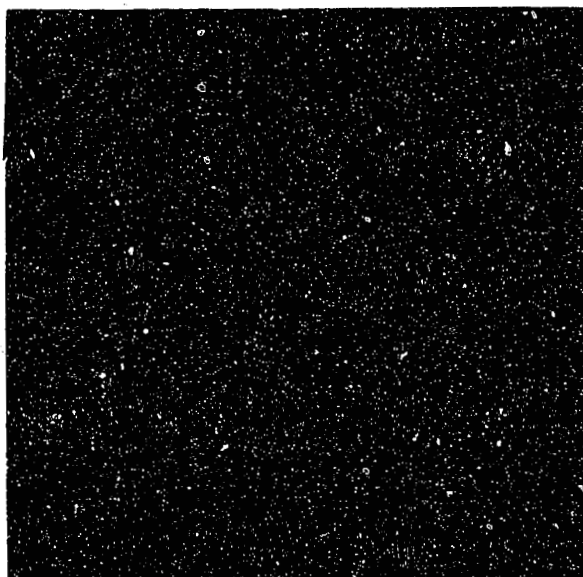100 feet downstream from end
sill. (2-hour scour test)

D. 45° wing walls replacing 90°
walls of Basin No. 1. (2-
hour scour test)

CACHUMA DAM SPILLWAY
Scour Patterns for Basin No. 1 and Modified Basin No. 1
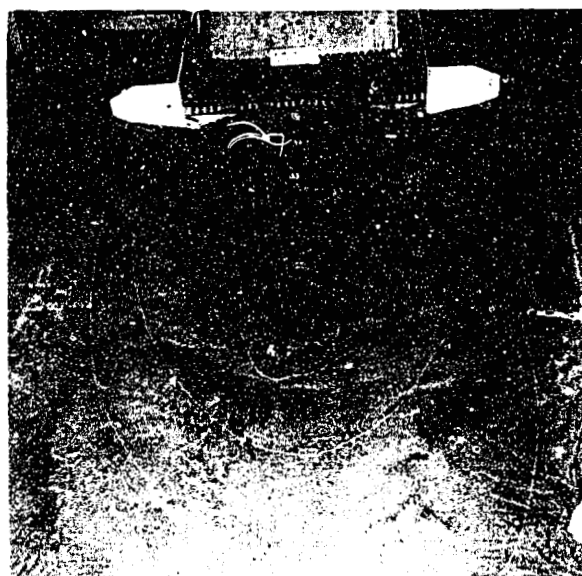After Discharge of 161,000 second-feet for 1/2 and 2 hours
1:60 Scale Model

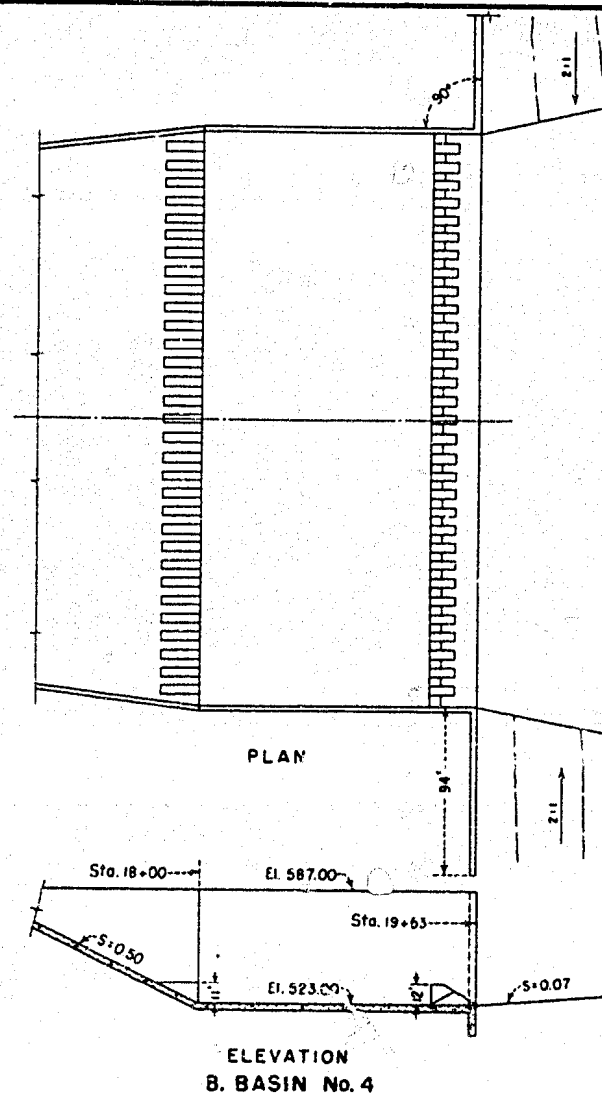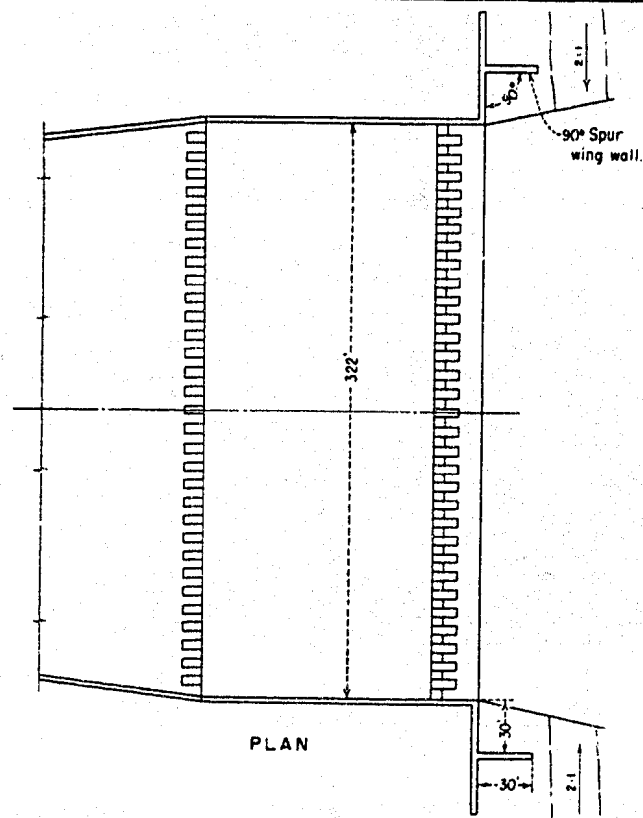Figure 23
Report Hyd-354

A. Basin No. 2

B. Basin No. 3

C. Basin No. 4

D. Basin No. 5 (Recommended)
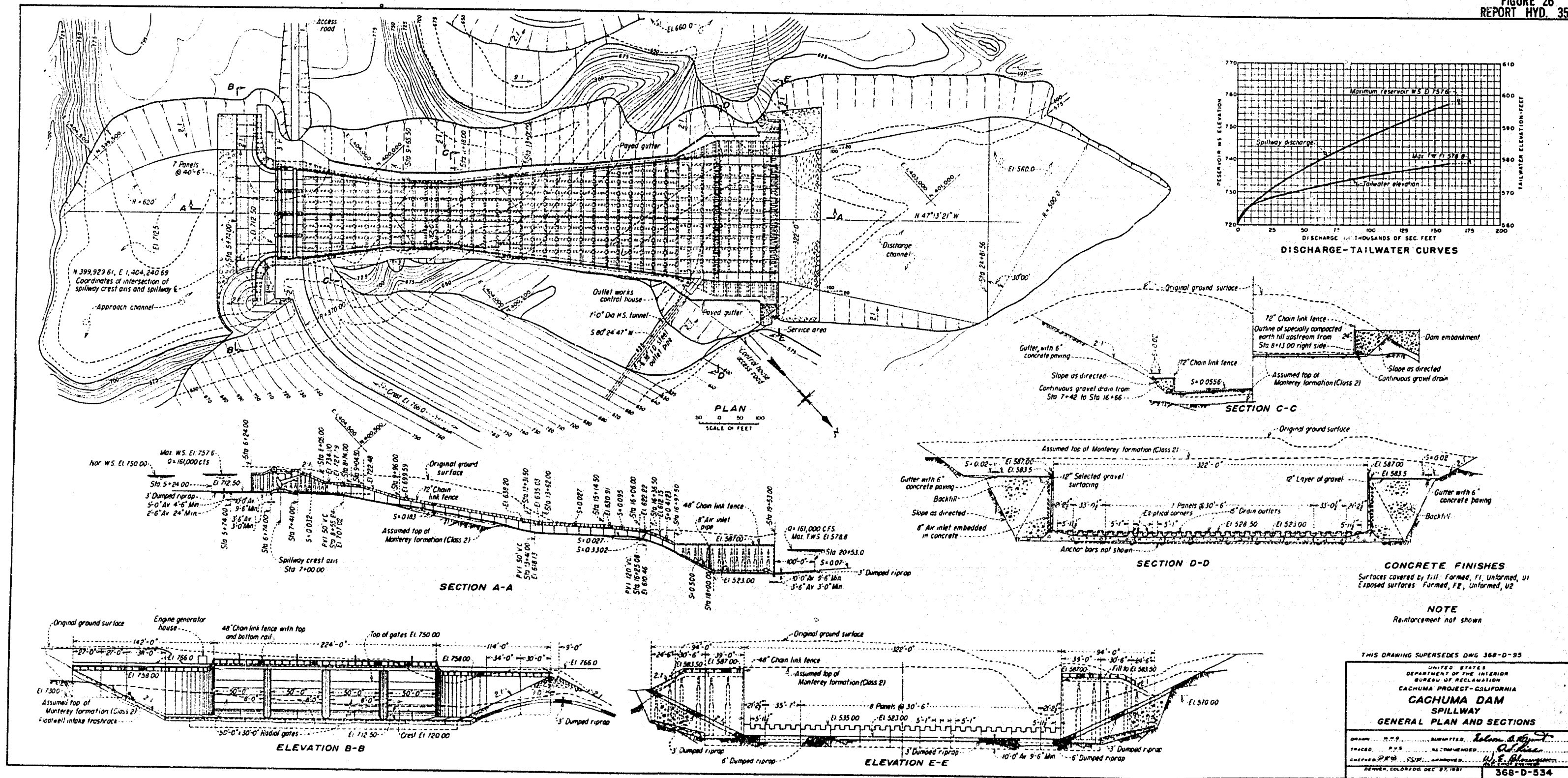
CACHUMA DAM SPILLWAY
Scour Patterns for Basin No. 2 to 5
After Discharge of 161,000 second-feet for 2 hours
1:60 Scale Model

PLAN

Sta. 18+00   El. 587.00
Sta. 19+53
S=0.50
5.5'
El. 523.00
S=0.17

ELEVATION
A. BASIN No. 3

90° Spur
wing wall.

322'

30'
30'
2:1

PLAN

Sta. 18+00   El. 587.00
Sta. 19+63
S=0.50
El. 523.00
S=0.07

ELEVATION
B. BASIN No. 4

90°

94'

2:1

STILLING BASINS No. 3 AND 4
CACHUMA DAM SPILLWAY
1:60 SCALE MODEL STUDY

FIGURE 24
REPORT HYD. 354

FIGURE 26
REPORT HYD. 354

DISCHARGE-TAILWATER CURVES

PLAN

SECTION C-C

SECTION D-D

SECTION A-A

CONCRETE FINISHES
Surfaces covered by fill - Formed, F1, Unformed, U1
Exposed surfaces - Formed, F2, Unformed, U2

NOTE
Reinforcement not shown

ELEVATION B-B

ELEVATION E-E

THIS DRAWING SUPERSEDES DWG 368-D-95

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CACHUMA PROJECT - CALIFORNIA
CACHUMA DAM
SPILLWAY
GENERAL PLAN AND SECTIONS
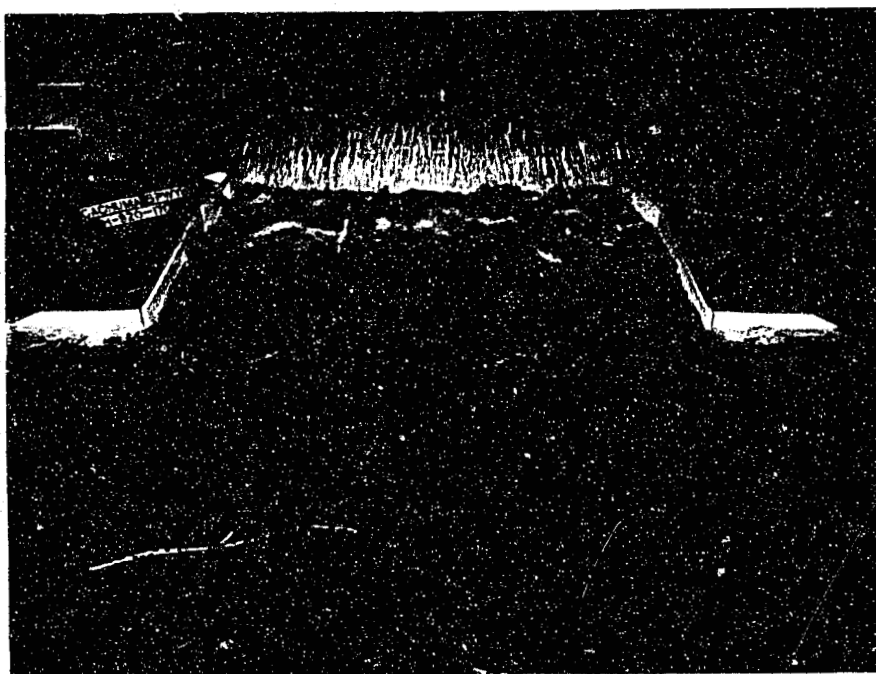
DENVER, COLORADO, DEC 27, 1951

368-D-534

Figure 27
Report Hyd-254

A. Two 30-inch Hollow Jet valves discharging the maximum outlet works discharge of 354 second-feet. Zero flow in spillway.

B. Flow distribution downstream from basin. Discharge = 100,000 second-feet (approximately maximum discharge at normal reservoir elevation) outlet works discharge = 0.
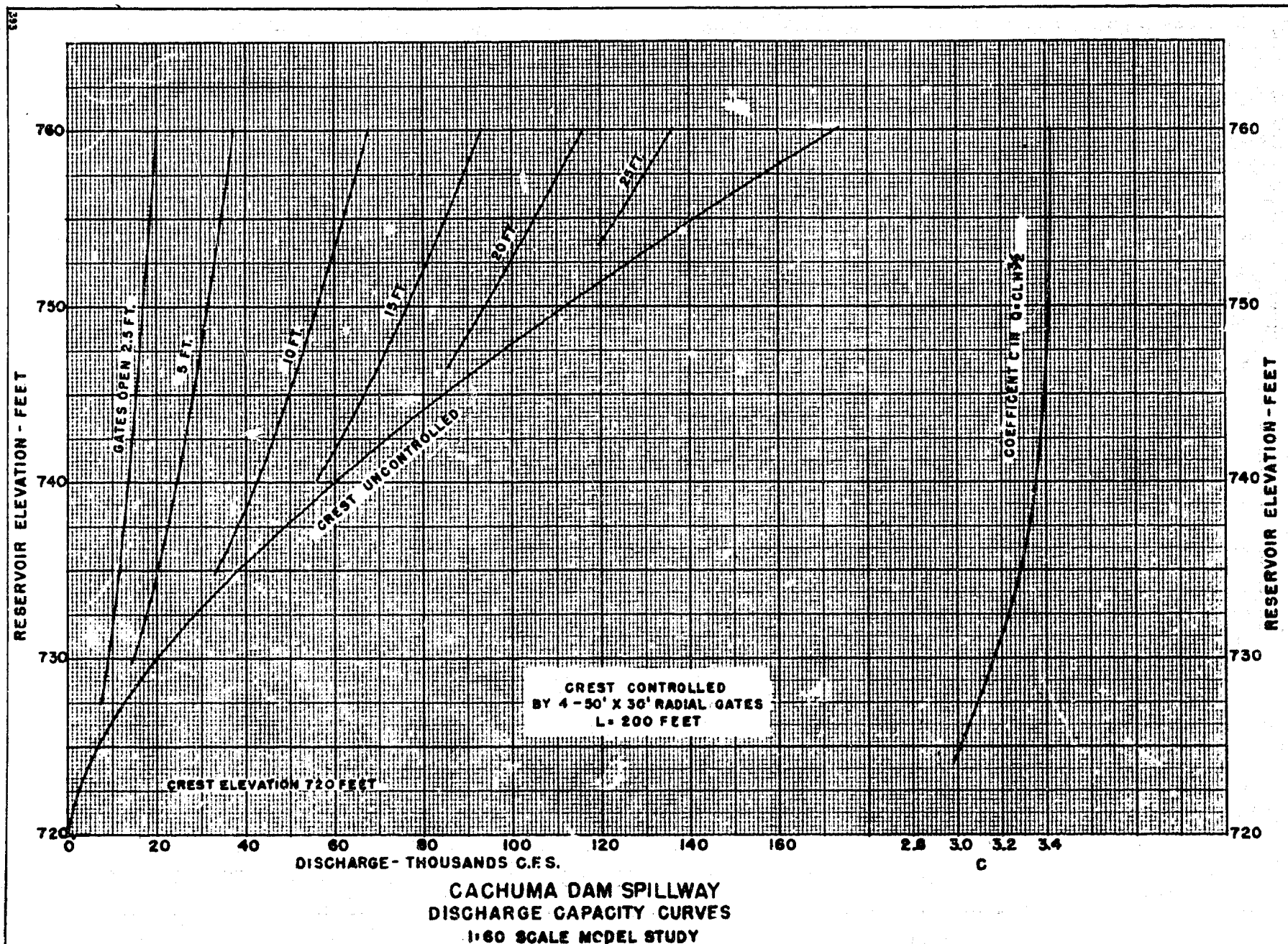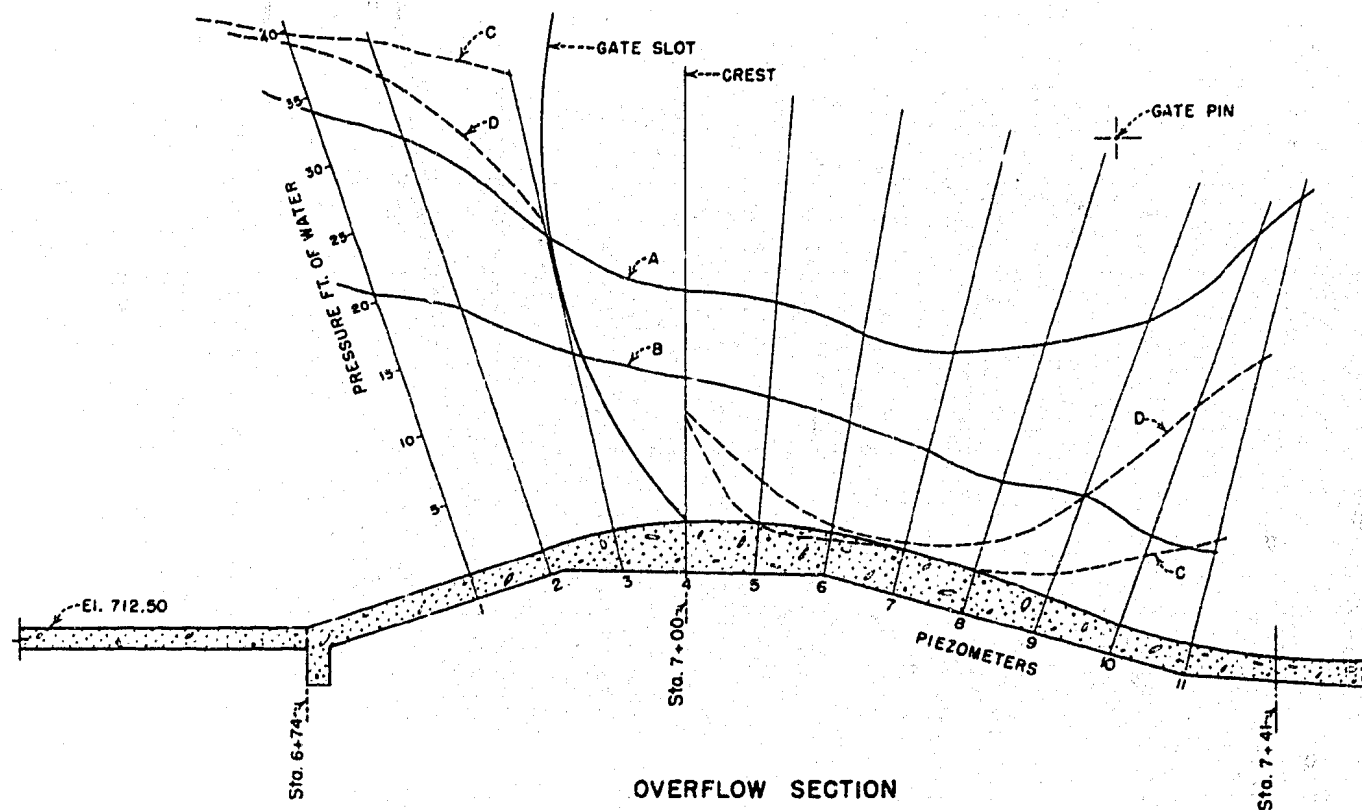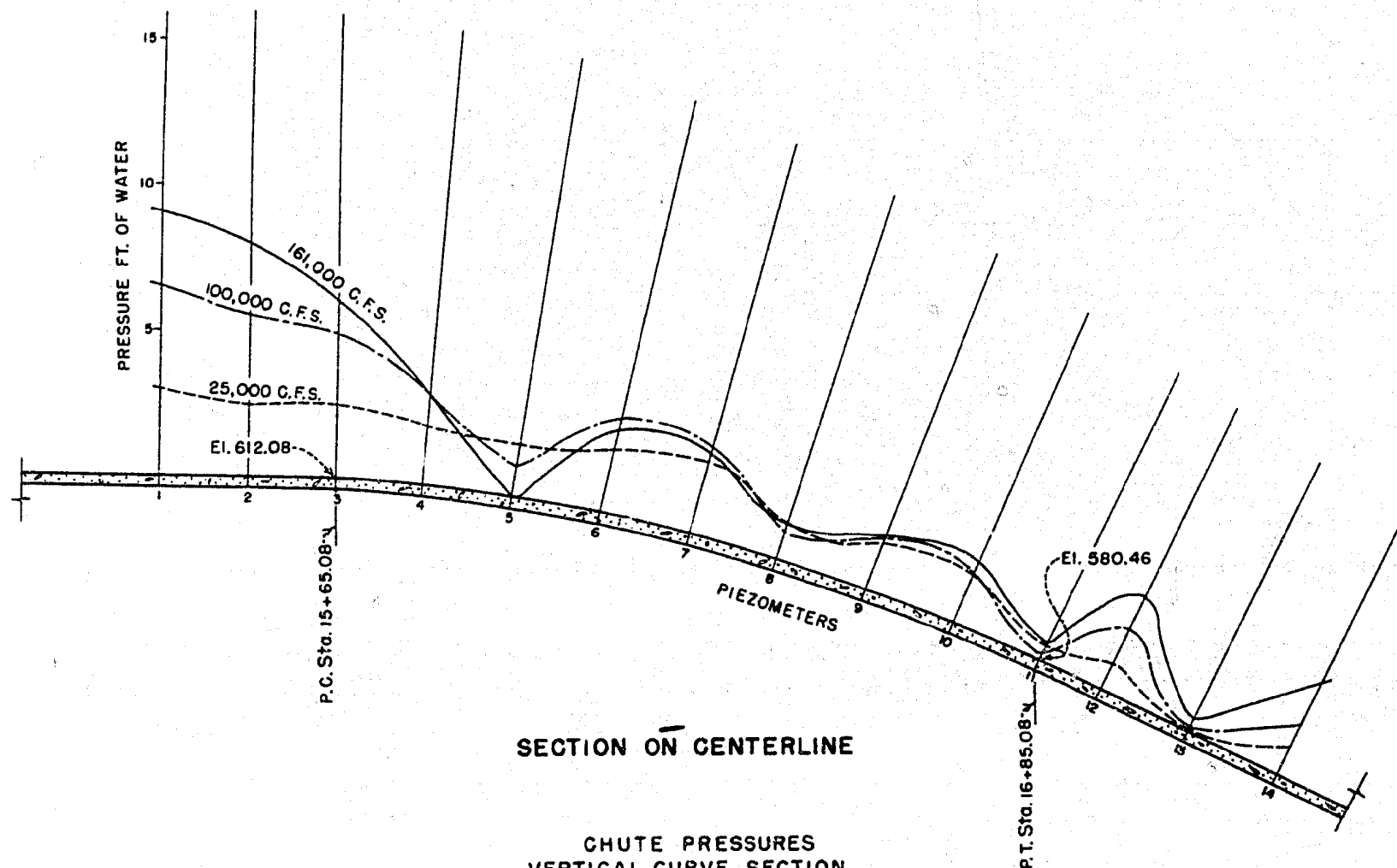
CACHUMA DAM SPILLWAY
Operation of Outlet Works and Recommended Spillway
1:60 Scale Model

CACHUMA DAM SPILLWAY
DISCHARGE CAPACITY CURVES
1:60 SCALE MODEL STUDY

FIGURE 28
REPORT HYD. 354

FIGURE 29
REPORT HYD. 354

OVERFLOW SECTION

LINE	CURVE	RES. EL.	DISCH.	GATE
————	A	758.1	160,000	FULL OPEN
————	B	739.5	57,600	FULL OPEN
— — — —	C	755.8	19,100	2.5' OPEN
— — — —	D	758.0	36,000	5' OPEN

OVERFLOW SECTION PRESSURES
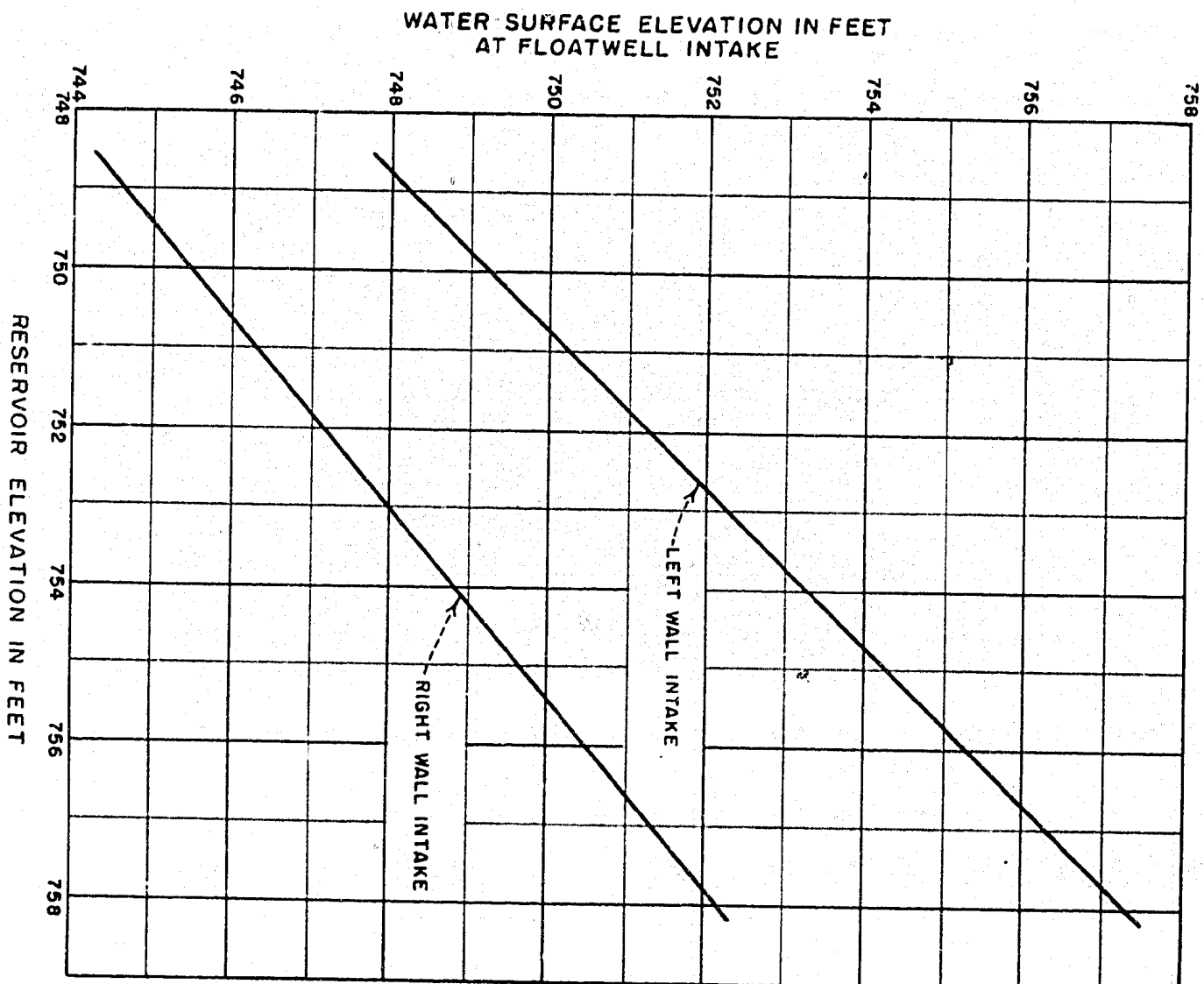RECOMMENDED SPILLWAY
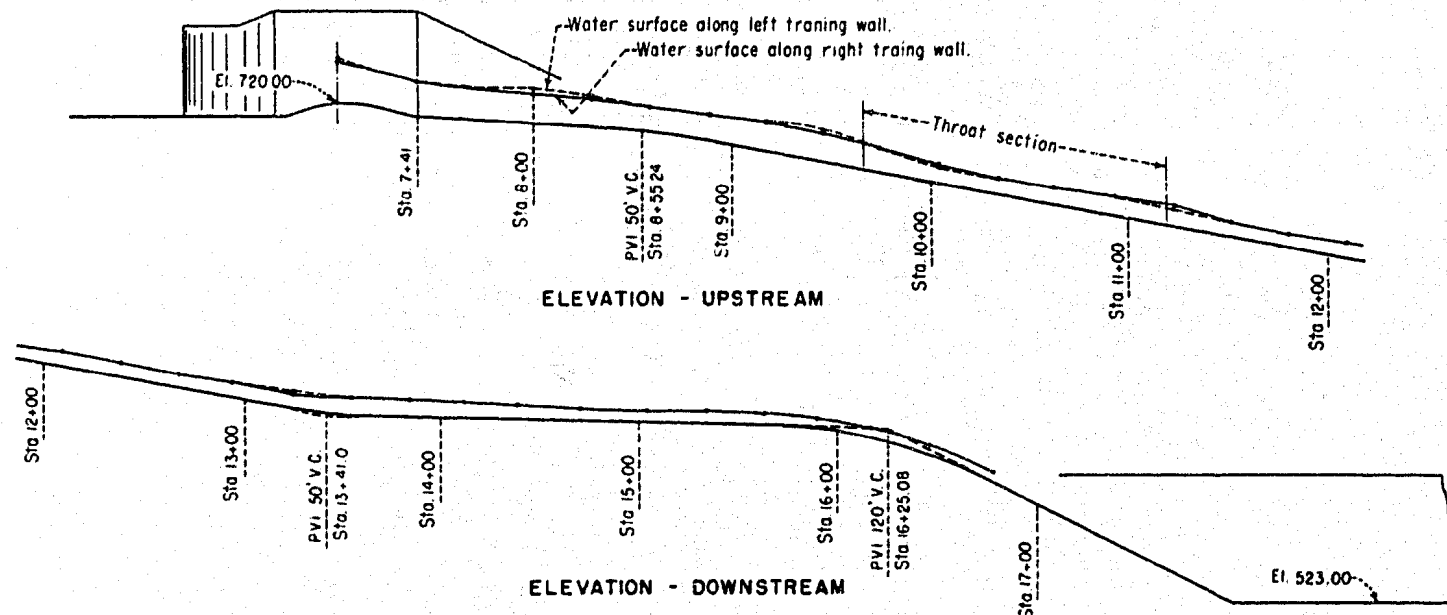CACHUMA DAM
1:60 SCALE MODEL STUDY

SECTION ON CENTERLINE

CHUTE PRESSURES
VERTICAL CURVE SECTION
RECOMMENDED SPILLWAY

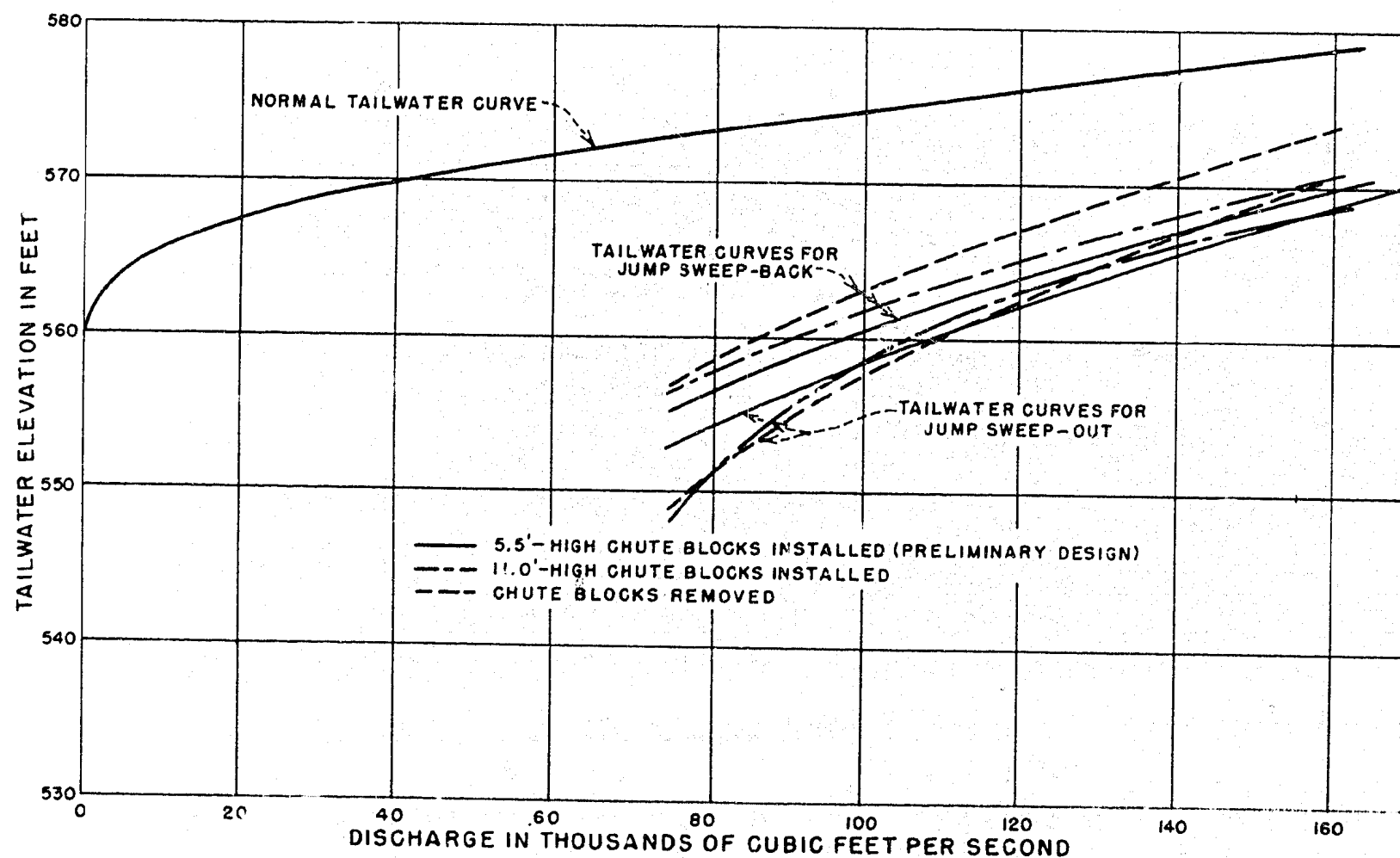CACHUMA DAM

1:60 SCALE MODEL STUDY

FIGURE 30
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FIGURE 31
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WATER SURFACE ELEVATION IN FEET
AT FLOATWELL INTAKE

RESERVOIR ELEVATION IN FEET

LEFT WALL INTAKE

RIGHT WALL INTAKE

CACHUMA DAM SPILLWAY
WATER SURFACE ELEVATIONS AT FLOATWELL INTAKES
1:60 SCALE MODEL
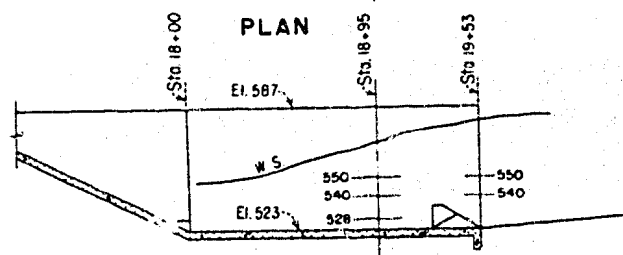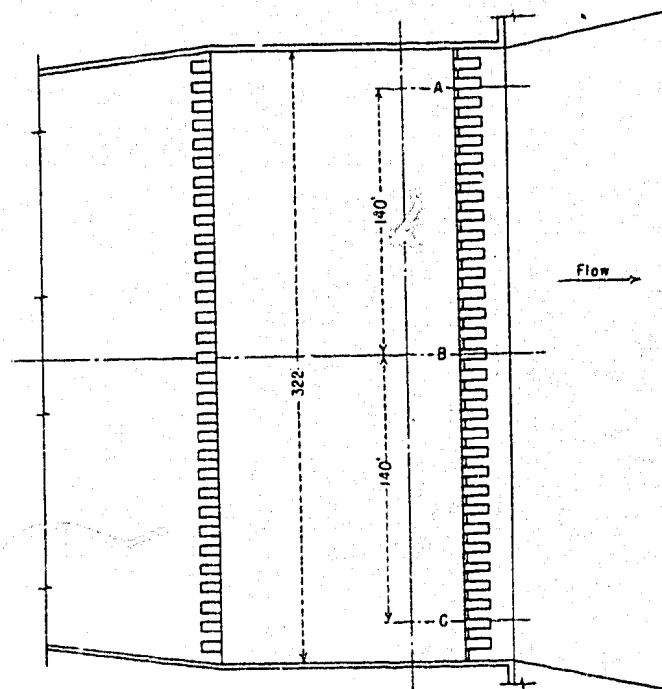
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ELEVATION - UPSTREAM

ELEVATION - DOWNSTREAM

TABULATED DEPTHS ALONG TRAINING WALLS

STATION	RIGHT WALL DEPTH-FEET	LEFT WALL DEPTH-FEET	STATION	RIGHT WALL DEPTH-FEET	LEFT WALL DEPTH-FEET	STATION	RIGHT WALL DEPTH-FEET	LEFT WALL DEPTH-FEET	STATION	RIGHT WALL DEPTH-FEET	LEFT WALL DEPTH-FEET
7+20	20.90	22.50	12+37.5	6.55	7.20	9+74	11.90	12.50	14+68.7	6.55	6.85
7+41	17.50	17.50	12+66	6.90	7.20	10+03.2	8.15	7.50	15+01	6.25	6.25
7+995	15.00	15.35	12+94.7	7.50	7.50	10+32.5	8.30	7.20	15+30.5	6.55	5.00
8+28.7	13.75	12.50	13+23.5	7.85	8.45	10+61.2	8.10	8.45	15+60	5.00	4.65
8+58	12.80	13.75	13+53	8.75	8.45	10+91.5	9.35	8.75	15+89	5.60	4.35
8+872	13.75	13.10	13+82.5	8.75	8.45	11+20.7	10.30	9.10	16+18	4.40	4.05
9+16.5	14.70	14.75	14+09.5	8.15	8.15	11+49.5	6.55	6.60	16+46.5	4.10	4.05
9+45.2	14.10	15.90	14+38.5	7.20	7.50	11+78.7	6.60	6.60	16+75.0	4.05	4.35
						12+08	6.60	6.55			

WATER SURFACE PROFILES FOR 110,000 C.F.S.
RECOMMENDED SPILLWAY
CACHUMA DAM
1:60 SCALE MODEL STUDY

FIGURE 33
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NORMAL TAILWATER CURVE

TAILWATER CURVES FOR
JUMP SWEEP-BACK

TAILWATER CURVES FOR
JUMP SWEEP-OUT

TAILWATER ELEVATION IN FEET

——— 5.5'-HIGH CHUTE BLOCKS INSTALLED (PRELIMINARY DESIGN)
— - — 11.0'-HIGH CHUTE BLOCKS INSTALLED
— — — CHUTE BLOCKS REMOVED

DISCHARGE IN THOUSANDS OF CUBIC FEET PER SECOND

CACHUMA DAM SPILLWAY
TAILWATER AND JUMP SWEEP-OUT CURVES
1:60 SCALE MODEL
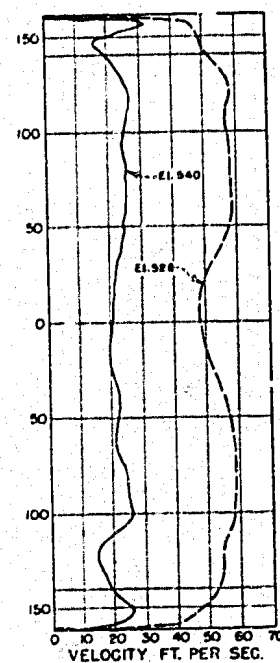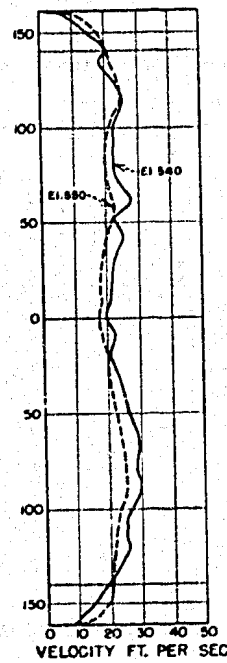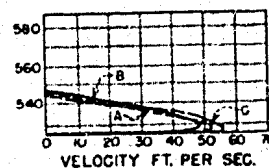
PLAN

Flel 587-

W S

El. 523-

ELEVATION
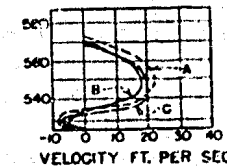
HORIZONTAL VELOCITY CURVES

VERTICAL VELOCITY CURVES

VELOCITY DISTRIBUTION AT 161,000 C.F.S.
SPILLWAY STILLING BASIN−RECOMMENDED
CACHUMA DAM
1:60 SCALE MODEL STUDY

FIGURE 34
REPORT HYD. 354